Preliminary Analysis of Infrastructural Failures and their Associated Risks and Consequences Related to Biota Transfers Potentially Realized from Interbasin Water Diversion

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List of Acronyms

alternating current	AC
American Society of Mechanical Engineers	ASME
American Water Works Association	AWWA
American Water Works Association Research Foundation	AwwaRF
American National Standards Institute	ANSI
American Society for Testing and Materials	ASTM
American Society of Civil Engineers	ASCE
aquatic nuisance species	ANS
aquifer storage and recovery	ASR
as low as reasonably practicable	ALARP
below ground surface	BGS
Best Management Practices	BMPs
Biota Transfer Report	BTR
Bureau of Indian Affairs	USBIA
Cambridge Scientific Abstracts	CSA
Centers for Disease Control and Prevention	CDC
Columbia Environmental Research Center	CERC
Dakota Water Resources Act	DWRA
Department of Defense	USDOD
Department of the Interior	DOI
direct current	DC
Disinfectant-Disinfection By-Product	D-DBP
Disinfectants and Disinfection By-Products Rule	DBPR
disinfection byproducts	DBPs
dissolved air filtration	DAF
dissolved organic matter	DOM
Draft Environmental Impact Statement	DEIS
ductile iron pipe	DIP
Ductile Iron Pipe Research Association	DIPRA
Electric Power Research Institute	EPRI
Enhanced Surface Water Treatment Rule	ESWTR
Earth Resources Observation and Science	EROS
failure mode and effects analysis	FMEA
fault-probability trees	FPTs
full-time equivalent	FTE

List of Acronyms (continued)

Garrison Diversion Unit	GDU
GDU Import to Sheyenne River	GDUISR
geographical information systems	GIS
Habitat Equivalency Analysis	HEA
haloacetic acids	HAAs
hazard assessment-critical control process	HACCP
high density polyethylene	HDPE
intergranular stress corrosion cracking	IGSCC
Interim Enhanced Surface Water Treatment Rule	IESWTR
International Common Cause Data Exchange	ICDE
International Joint Commission	IJC
Life-Cycle Assessment	LCA
Long Term 2 Enhanced Surface Water Treatment Rule	LT2ESWTR
Maintenance Free Operating Period	MFOP
Maximum contaminant level	MCL
maxmium daily residue load	MDRL
mean-time-between-critical-failure	MTBCF
Mean-time-to-failure	MTTF
Mean Time to Repair	MTTR
Mean Time Between Failure	MTBF
mechanical joint	MJ
Missouri River Import to Red River Valley	MRIRRV
molecular weight	MW
molecular weight cut off	MWCO
Municipal, Rural and Industrial	MR&I
National Association of Corrosion Engineers	NACE
National Earthquake Information Center	NEIC
National Invasive Species Council	NISC
National Environmental Policy Act	NEPA
National Park Service	NPS
natural organic matter	NOM
Natural Resource Conservation Service	NRCS

List of Acronyms (continued)

Offshore Reliability Data	OREDA
operations and maintenance	O&M
oriented PVC	OPVC
polyvinyl chloride pipe	PVC
probability of exceedance	PE
rate of occurrence of failures	ROCOF
Reclamation Dakota Area Office	DAO
Reliability Data Collection and Maintenance Rule implementation	BDATA, Spain
Reliability Data, Centralized Data Base	ZEDB, Germany
reverse osmosis	RO
rights-of-way	ROWs
Safe Drinking Water Act	SDWA
scientific and natural areas	SNAs
STATSGO	State Soil Geographic database
steel pipe	ST
stress corrosion cracking	SCC
sulfate-reducing bacteria	SRB
Supervisory Control and Data Acquisition System	SCADA
Supplemental Draft Environmental Impact Statement	SDEIS
Surface Water Treatment Rule	SWTR
The Nature Conservancy	TNC
total suspended solids	TSS
transgranular stress corrosion cracking	TGSCC
trihalomethanes	THMs
Ultraviolet	UV
US Department of Agriculture	USDA
US Fish and Wildlife Service	USFWS
US Forest Service	USFS
US Geological Survey	USGS
Visual Basic Application	VBA
welded steel pipe	WST
Welded Steel Pipe	WSP
wildlife management areas	WMAs

Executive Summary

Under the auspices of the Dakota Water Resources Act (DWRA) of 2000, the Secretary of the Interior has been directed to conduct a comprehensive study of the water quality and quantity needs of the Red River Valley and the options for meeting those needs. The Dakota Area Office, Bureau of Reclamation (Reclamation) requested technical support from the US Geological Survey (USGS) Columbia Environmental Research Center (CERC) for an evaluation of the risks and economic consequences of biota transfers potentially associated with interbasin water transfers that might occur between the Upper Missouri River and the Red River of the North (Red River) basins (USGS 2005a,b). This report is the third in a series of technical analyses focused on potential risks associated with interbasin water transfers. For this technical report, Reclamation requested USGS complete a supplemental evaluation of risks associated with failures in infrastructure proposed for interbasin diversions of Missouri River source waters to Red River Valley. Although proposed engineering designs are early in their conceptual development, biota transfers are considered for each of the interbasin water diversion alternatives. The primary focus of this preliminary analysis was infrastructure failure (e.g., in pipes, pumps, valves, motors, or their components of the water transmission system) in any of these alternative systems that may be linked to interbasin biota transfers.

This supplemental report summarizes the technical findings of CERC staff and their Department of the Interior (DOI) partners in the National Park Service (NPS) with respect to risks and consequences potentially associated with infrastructure failures linked to interbasin biota transfers. Four alternatives characterized by Reclamation in their Draft Environmental Impact Statement (DEIS; Reclamation 2005) that involve an interbasin water diversion were considered in this preliminary analysis of infrastructural resulting in biota transfer between Missouri River and Red River basins. In parallel with this preliminary analysis of infrastructural failures and interbasin biota transfers, a preliminary analysis of potential economic consequences associated with biota transfers was completed for Sheyenne River and Lake Ashtabula.

Infrastructural Failure, Interbasin Biota Transfers, and Proposed Alternatives Involving Water Diversions Between Missouri River and Red River Valley. This preliminary failure analysis complements previous work focused on risks and economic consequences associated with biota transfer between Missouri River and Red River basins (USGS 2005a,b). These technical support efforts were primarily focused on a wide ranging list of biota of concern that included prokaryotic organisms (e.g., bacteria such as serotypes of *Escherichia coli* and *Salmonella* spp. and cyanobacteria), protozoa and myxozoa (with a particular focus on parasites and disease-causing organisms such as *Yersinia ruckeri*, *Myxosoma cerebralis*, *Cryptosporidum parvum*, and *Giardia lamblia*), aquatic invertebrates (e.g., zebra mussel, *Dreissena polymorpha*, and New Zealand mudsnail, *Potamopyrgus antipodarum*), and fishes (see USGS 2005a for additional detail on biota of concern), and risk reduction measures associated with various engineering options summarized in DEIS (Reclamation 2005). The preliminary risk reduction analysis summarized in USGS (2005b) focused on the prospects of failure across each of the four alternatives involving interbasin water diversions. In USGS (2005a,b) system failures had been identified as critical to higher resolution analysis, and as a consequence became the primary driver behind the analysis detailed in this report. As in the preceding reports in this series of technical support documents, costs were not included as part of the risk reduction analysis in USGS (2005b), and have been deferred to future engineering analyses necessary for design and engineering cost-benefit analysis.

Overall risk characterization and attendant uncertainties. USGS (2005a) suggested greatest risk reduction would be achieved through a water transfer mediated in the presence of a control system that included treatment of intake water at the source and transmission via closed conveyance from Missouri River basin to Red River basin. Results of the simulation study suggested that risks of biota transfers under such a controlled, closed-conveyance scenario would range from 10^{-6} to less than 10^{-9}. In the absence of an accompanying analysis of failures in water transmission systems, categorical assignments of risk reduction credits in USGS (2005b) suggested that greatest reduction of risks of interbasin biota transfers might be gained through the Garrison Diversion Unit (GDU) Water Supply Replacement Pipeline, although the Missouri River Import to Red River Valley was identified as an Action Alternative that may provide sufficient risk reduction in the absence of microfiltration, given withdrawal of intake water is accomplished using a network of radial collector wells at the Missouri River source. USGS (2005b) also noted that open-water conveyance of treated waters via the Sheyenne River adversely affected the risk reduction credit score for the GDU Import to Sheyenne River alternative. Reservoir storage of treated waters in Lake Ashtabula may present similar risks with respect to biota transfers.

Despite the preliminary outcomes of the risk reduction analysis, USGS (2005b) suggested that similarities in proposed designs for each Action Alternative might provide sufficient margin of safety in risk management, depending on system user's risk tolerance. The preliminary risk reduction analysis also observed that full design engineering analysis, including costs, would facilitate selection among alternatives. In fully designed systems, discrimination among Action Alternatives might be increased through greater focus on risks associated with routes of transmission pipelines or specific treatment regimens. For example, the reciprocal character of engineering risks were captured in the initial categorical risk reduction analysis where a high score for risk reduction was assigned to pipeline features characteristic of GDU Water Supply Replacement Pipeline alternative, yet a low score was tendered for risk reduction related by pipeline breaks, since the occurrence of pipe breaks would be greatest in the system designed with most pipeline miles. This assumption also does not discriminate between risks linked to other attributes of a water transmission system such as pipe diameter, which is critical in engineering evaluations that might follow as part of a hydraulic analysis completed for full designs coming from winnowing of Action Alternatives.

Given this context, the categorical analysis of USGS (2005b) was extended in the current investigation to address pipeline attributes, particularly pipe diameter and pipeline route (considered as linear miles, assuming sensitive habitats were avoided). As in the preliminary risk reduction analysis (USGS 2005b), even with addition of these attributes to the analysis, each of the Action Alternatives were closely aligned. In contrast to the risk reduction scores derived in the preliminary risk reduction analysis, however, the priority ranking of Action Alternatives in ascending order was, GDU Import Pipeline < GDU Import to Sheyenne River = GDU Water Supply Replacement Pipeline < Missouri River Import to Red River Valley. These differences in risk reduction rankings resulted when attributes linked to pipe diameter and pipeline lengths were incorporated into the analysis. In USGS (2005b), a simple category “pipeline” served as the only measure related to conveyance—if treated water was piped, reduced risk was achieved, and the discriminating attribute was pipeline length—and has been elaborated upon in this extended analysis. For example, GDU Water Supply Replacement Pipeline displayed highest score for risk reduction credits in USGS (2005b), but switched positions with Missouri River Import to Red River Valley in this extended analysis, because of its greater dispersion in pipe diameters throughout its proposed route. Regardless of the closed conveyance of treated water throughout its course of transmission yielding greatest risk reduction credits, pipeline length also confers risk not fully captured in the preliminary categorical analysis, particularly with respect to prospects of an engineering failure conditioning risks of biota transfer.

As evident in this extended risk reduction analysis, priority listings of Action Alternatives that involve an interbasin water transfer are relatively more sensitive to pipe diameter and pipeline routing attributes than treatment attributes at this stage of conceptual design. Each alternative shares common starting points for proposed water treatment regimens—sedimentation, flocculation, and coagulation in conjunction with chlorination and chloramination—and once engineering options are detailed with respect to efficacy and costs associated with additional treatment options (e.g., UV disinfection, media or membrane filtration processes, or alternatives yet to be identified such as dissolved air flotation, or DAF), an updated risk reduction analysis may be incorporated into engineering analyses.

Low probability-high consequence events likely remain even under the most controlled engineering practice implemented for an interbasin water transfer or under a no-action alternative. The alternatives considered in this and previous analyses (USGS 2005a,b) reflect a range of "best practices" available to Reclamation and stakeholders confronting the water supply issues of the Red River Valley. Each of these Action Alternatives may be equally foiled by stochastic events reflected in the biota transfer–species invasion process, yet the engineering options outlined by Reclamation (2005b,c) provide starting points for refined engineering analysis of risks and costs, or continued development of feasibility designs. As alternatives are selected and moved forward in developing resource management plans, a framework for developing long-term monitoring programs will evolve as part of the operation and maintenance of the water transmission and distribution network to minimize failures in the water transmission and distribution network.

Engineering attributes of water transfer control systems provide the primary countermeasures to minimize risks associated with biota transfer, given technologies developed in each of the Action Alternatives. Each proposed biota-water treatment plant is predicated on treatment of source waters to reduce risks associated with biota transfers potentially realized as events collateral to an interbasin water diversion. Reclamation has considered a range of biota-water treatment options in parallel with their identifying alternatives considered in the DEIS (see Reclamation 2005c), which will be extended in the Supplemental Draft Environmental Impact Statement (SDEIS) targeted for release and comment in late 2006. As presently identified and characterized in the DEIS, water treatment is a component in each Action Alternative, including a conventional pretreatment that involves coagulation, flocculation, and sedimentation. These pretreatment steps are typical of water treatment facilities, including an initial physical screening of source waters wherein physical debris (e.g., leaves, logs, sticks, litter such as plastic bottles), large invertebrates and fishes are removed from intake water drawn into the treatment plant. Following removal of physical debris and larger biota, intake water will pass through a series of conventional chemical treatments— coagulation-flocculation-sedimentation—intended to remove suspended solids and some impurities from raw waters. These three conventional treatment steps reduce or remove suspended solids which improves the appearance and taste of drinking water, reduces or removes some microbiological contaminants that might be harmful to humans. The intended outcomes of pretreatment are enhanced system performance, e.g., in systems relying on UV disinfection, reducing TSS and benefit water treatment. Depending on the engineering design, a "presedimentation" step may be included to remove settleable solids present in the water by gravity prior to conventional chemical treatment. Dissolved chemicals contributing to water hardness (e.g., iron, manganese) are removed by lime softening or by the addition of potassium permanganate as a pretreatment to precipitate metal salts, since the conventional process does not remove dissolved solids. As necessary, lime softening is incorporated into conventional treatment by the addition of lime between the flocculation and coagulation phases of the process.

Once raw water has passed through conventional treatment, various options are available to engineering design, including filtration and disinfection. Filtration options range widely, e.g., media filtration, often times sand or other granular materials, or membrane filters of various porosities, but all target removal solids and fine particles of various sizes, depending on the system's design. Disinfection options vary, depending on water's specified end-use. In general, the disinfection process inactivates waterborne pathogens to assure safe consumption, e.g., for human populations, domestic animals, or application to other water uses (e.g., industrial applications, agriculture). Although not indicated in all water uses, water softening may also be incorporated into a system's design in order to remove minerals (primarily calcium and magnesium) that contribute to water hardness.

Various chemical and physical options currently applied to water treatment requirements pursuant to regulatory requirements, e.g., LT2ESWTR and SDWA as amended specify minimum acceptable inactivation necessary for public water to be considered potable, including regulations that specify minimum disinfection of (1) 3 log (99.9%) for *G. lamblia* cysts and (2) 4 log (99.99%) for enteric viruses (see Letterman 1999, see also http://www.epa.gov/safewater/sdwa/index.html last accessed December 8, 2004). By extension of these benchmark values based on life history attributes of indicators such as *Cryptosporidium* spp., tools are available to the disinfection process targeted on concerns associated with biota transfer related to interbasin water diversions. Regardless of the target indicators serving as surrogates for endpoints other than public health, water quality characteristics influence disinfection processes, e.g., turbidity and pH strongly affect contact time necessary to achieve target level of disinfection. Microorganisms have varying sensitivities to disinfectants. If an organism has a high resistance to a certain disinfectant, contact time will be greater than for an organism with a low resistance.

Potential selection of resistant forms also varies, e.g., in biofilms formed in the transmission and distribution system.

Depending on the final design specifications of the treatment system, various levels of disinfection can be attained such as altering UV dose or type of physical barrier (e.g., media or membrane filtration) incorporated into system's design. For example, selection of disinfection technology can be determined once regulatory and management needs are addressed, and once the level of disinfection is specified, engineering designs can be developed to yield the necessary contact time for a given level of disinfection. As presently configured and presented in the DEIS (Reclamation 2005c), and in the absence of evaluating costs or associated benefits and liabilities, a preliminary analysis of Action Alternatives relative to their risk reduction potential has been completed and placed within the context of the range of risks characterized in USGS (2005).

The frequency of control system failures—be those water withdrawal, treatment, or transmission related—will necessarily reflect system performance as a function of time. For example, pipe breaks and the risks that might be associated with subsequent biota transfers are low probability-high consequence events following the potential highly variable start up to system operation, but will likely increase as the system ages. Similar performance behaviors would be anticipated for other components of the system, again, all being linked to the aging process for materials and the mechanical functions each component plays in the water withdrawal, treatment, and transmission system. Perhaps more importantly, system performance could be nominal through much of the system's service life, yet very low probability events, e.g., undetected short-circuiting in membrane units, could be associated with system failures manifested as biota releases to the transmission system, wherein entrainment in piping and pipe fittings could yield colonization of biofilms with biota of concern that eventually are transferred to the importing region. Pipeline breaks and their role in evaluating the life cycle of a water transmission and distribution network should not be undervalued, particularly given stakeholder concern on biota transfer issues throughout the history of the Garrison Diversion (USGS 2005).

Regardless of the failure modes, these low probability-high consequence events should be incorporated into long-term management plans for the water system regardless the alternative selected. Once an alternative is selected for addressing the water needs of the Red River Valley, engineering designs can go beyond existing industry-wide experience on pipe breaks as summarized in Section 3 and gather system-specific data. Life-cycle management of buried pipe should assess the condition of buried pipe throughout the course of the network, manage and mitigate the network's deterioration, and develop safe and cost-effective asset management plans to minimize unexpected outages and minimize long-term costs, be those monetary or primarily non-monetary, e.g., related to collateral events such as biota transfers.

Currently, about 80% of North American utilities rely on DIP and about 10% rely on plastic pipe, with other pipe materials accounting for the balance (AwwaRF 2006). AwwaRF and the National Research Council of Canada provide a method to translate distress indicators obtained visually or from nondestructive evaluation techniques on large water transmission lines into condition ratings. Similarly, techniques for monitoring structural behavior of pipeline systems has focused on continuous-monitoring techniques to evaluate structural performance of operationally critical water pipelines, including recommendations for combined screening, monitoring, and condition assessment techniques to evaluation structural performance of pipelines.

Although preliminary failure analysis focused on interbasin water diversions (USGS 2005a,b), in-basin alternatives must not be interpreted as being "risk free." Under in-basin alternatives currently outlined in the DEIS (Reclamation 2005)—North Dakota in-basin alternative, Red River basin alternative, or Lake of the Woods alternative—risks of interbasin biota transfers would be practically zero. As with a No-Action Alternative, in the absence of infrastructure needed to implement an interbasin water diversion, pathways directly linking Missouri River and Red River basins would not be completed under these alternatives. However, risks of biota transfers and species invasions associated with biota exchanges between Missouri River and Red River basins would not be eliminated. For example, in addition to biota transfers associated with competing pathways realized during stochastic environmental events, e.g., floods and seasonal weather extremes, construction-related activities associated with any of the proposed projects would yield transient or permanent disruption to habitats in the area of concern, and these disruptions may directly or indirectly result in completed pathways and enable biota exchange between Missouri River and Red River basins. Construction-related activities could increase the likelihood of propagules being released to previously unoccupied habitat, depending on the type and extent of those activities. Secondary effects could also indirectly promote biota transfers, enhance species invasions, and alter metapopulation dynamics in the area of concern, although effects would be indirectly related to management actions to address water needs of the valley, and the project-specific activities would be characterized as being contributory factors in the biota exchange process (see USGS 2005, particularly Section 4 and uncertainty analysis).

For example, while the Lake of the Woods alternative represents a water diversion within HUC09, proposed water transfers would occur between sub-basins within HUC09 and may have risks associated with the potential completion of pathways enabling or continuing the dispersal of biota of concern presently in HUC0903 (e.g., Lake of the Woods occurs in 09030009), but available for expanding their distribution to HUC0902 (e.g., Upper Red River occurs in 09020104) through water transfers envisioned as part of this Lake of the Woods alternative. Past experience, e.g., rainbow smelt invasion of Lake of the Woods, would suggest that close proximity to Great Lake basin (HUC04) or other source areas might enable or promote continued biota transfers from that basin to sub-basins within HUC09 and areas immediately adjacent in HUC10 (see Appendix 7, USGS 2005). Although intrabasin water diversions were not considered in USGS (2005), the transfer of water between sub-basins may warrant consideration as far as enabling or promoting existing pathways of transfer from Great Lakes and Hudson Bay basins to both Red River and Missouri River basins. Although not an interbasin water transfer between 2-digit HUCs, the proposed action alternative transferring source waters from Lake of the Woods does reflect a transfer of source waters between sub-basins, and approximately 265 miles of pipeline would be involved in that transfer.

Regardless of selection of a No Action or Action Alternative, system integrity and reliability must be viewed within the context of uncertainty. For example, loss of containment commonly linked to pipe leaks, breaks, and bursts have historically been associated with a range of failure mechanisms, e.g., human factors (such as faults in construction and operation or other third-party actions), design flaws, materials failures, extreme conditions or environments, and most commonly and importantly, combinations of these factors. Materials failures commonly linked to pipeline failures include mechanical damage (e.g., linked to installation), fatigue cracks and other material defects, weld cracks (as might be encountered in joint-welded pipes), and external or internal corrosion. Metal fatigue in pipelines and other mechanical components of the water withdrawal, treatment, and transmission system are commonly linked to repeated cycling of the system load and the progressive local damage linked to fluctuating stresses and strains on the material, e.g., metal fatigue cracks will be initiated and propagated in regions where the strain is most severe. Uncertainties associated with fatigue failure may be considered early in system design through, e.g., eliminating or reducing stresses by changing pipeline configuration, streamlining pipe layout, or incorporate countermeasures to address unavoidable conditions. Pipeline design beyond those conceptual configurations in the DEIS (Reclamation 2005) will be critical to the risk reduction process, particularly those related to uncertainties reflected in this preliminary failure analysis. When considered in light of the ecological characterization of the project area, no better illustration of the interrelationships between pipeline and "habitat at risk" can be seen than that focused on stream crossings and pipeline installation relative to environmentally sensitive areas.

To address uncertainty and reduce risk potentially associated with biota transfers and to protect, e.g., fish and wildlife and their habitats, unaltered functionality of aquatic, terrestrial, and riparian ecosystems should be included as a design criteria for the transmission system. For example, pipeline installation should consider stream and wetland crossings within the context of Best Management Practices (BMP's) that reflect habitat assessments completed in conjunction with pipeline surveys necessary to the routing process. Pipeline crossings involve many processes that may impact the surrounding environment, including construction activities, habitat disturbance, removal of riparian and wetland vegetation, and the stream crossing itself. Direct impacts will likely be short-term, construction-related, and indirect or long-term impacts will depend on the type of crossing, construction techniques used for installation (e.g., trenching or horizontal directional drilling, if appropriate), and maintenance.

Similarly, rights-of-way (ROWs) may influence pipeline design and may be leveraged to reduce risk and attendant uncertainties as those relate to biota transfer. For example, managing revegetation subsequent to construction disturbance associated with pipeline installation may be critical to reducing uncertainties related to invasion by invasive species, perhaps not directly transferred to areas of concern via interbasin water diversions, but enabled to establish beach heads in disturbed habitats associated with pipeline installation. Construction practices yielding short-term disturbance habitats may unintentionally contribute indirectly to successful invasions, e.g., of plants considered in USGS (2005a). Effective management of construction-related effects potentially of concern to issues of biota transfer becomes a matter of bringing together the needs of transmission pipelines with those of biota dependent on habitats at risk. The use of habitat management and restoration techniques in ROWs management may serve long-term planning related to system performance (e.g., security from third party actions), while reducing uncertainties captured by biota transfers and species invasions.

Understanding and communicating uncertainties and limitations associated with full engineering designs should be incorporated into risk management plans for any Action Alternative regardless of whether it involves an interbasin water transfer or not. Developing these plans within the context of a system's life cycle directly addresses uncertainties reflected in the life time distribution of the system, which ultimately yields a more reliable system in its long-term operation and management. Life cycle analysis is a dynamic process that can help inform decision-makers, while reducing risks through design, construction, and operation of a system such as those envisioned to meet the water demands of the Red River Valley.

1.0 Introduction

Under the auspices of the Dakota Water Resources Act (DWRA) of 2000, the Secretary of the Interior has been directed to conduct a comprehensive study of the water quality and quantity needs of the Red River Valley and the options for meeting those needs. The Dakotas Area Office, Bureau of Reclamation (Reclamation) requested technical support from the US Geological Survey (USGS) Columbia Environmental Research Center (CERC) for an evaluation of the risks and economic consequences of biota transfers potentially associated with interbasin water transfers that might occur between the Upper Missouri River and the Red River of the North (Red River) basins (USGS 2005a,b). As part of that continuing technical support effort, Reclamation requested:

- a preliminary failure analysis of alternative systems involved in interbasin water diversions addressed in their Draft Environmental Impact Statement (DEIS) prepared by Reclamation as part of their National Environmental Policy Act (NEPA) compliance process. These water supply alternatives and water treatment options that have been proposed to meet water demands of the Red River Valley, and

- a preliminary evaluation of economic consequences potentially associated with these system failures. These economic consequences will be developed using Habitat Equivalency Analysis (HEA) as in previous biota transfer evaluations (USGS 2005a,b), and will be focused on the Sheyenne River of eastern North Dakota which has been included as part of the water transmission system under one alternative—the Import Missouri River waters via Garrison Diversion Unit (GDU) to Sheyenne River—and as part of another alternative potentially reliant on Lake Ashtabula as a storage reservoir.

As the third report in a series of technical analyses covering various aspects of risks potentially associated with interbasin water transfers between Missouri River and Red River basins, this technical analysis was completed by CERC staff and their Department of the Interior (DOI) partners in the National Park Service (NPS) and complements previous work on biota transfers (USGS 2005a,b). This report summarizes a preliminary analysis of risks potentially associated with failures in various infrastructure designs being considered for proposed interbasin diversions of Missouri River source waters to Red River Valley. Although engineering designs are early in their conceptual development, each of the alternatives includes risk reduction measures for biota transfers that may occur, depending on water supply alternatives. These risk reduction measures include proposed water treatment options to address concerns related to interbasin biota transfers. Infrastructure failure in any of these alternative systems may result in interbasin biota transfers, and failures in pipes, pumps, valves, motors, or other components of the water transmission system were considered primary elements of this preliminary failure analysis.

While the NEPA process is dynamic and represents ongoing dialogues among stakeholders, the technical analysis completed in parallel to the DEIS captures a snapshot in the evolving conceptual designs being considered to address the future water needs of the Red River Valley. Originally, four alternatives had been characterized by Reclamation in their DEIS (Reclamation 2005a) that involved an interbasin water diversion. These alternatives served as primary targets in this preliminary analysis of infrastructural failure and its role in mediating unintended biota transfers between Missouri River and Red River basins. In conjunction with this preliminary analysis of infrastructural failures and potential interbasin biota transfers associated with these failures, a preliminary analysis of economic consequences potentially realized in Sheyenne River and Lake Ashtabula was completed to address biota transfers, resulting from failures in infrastructure used to accomplish an interbasin water diversion. However, in the interval between the release of the DEIS and the USGS peer review of the draft failure and consequence analysis, two alternatives (Lake of the Woods and GDU Water Supply Replacement) were dropped from further consideration. Furthermore, the Missouri River Import to Red River alternative had originally incorporated a pipeline spur to Lake Ashtabula, anticipating the use of Lake Ashtabula as a supplemental storage reservoir as part of that alternative. That pipeline spur, however, has been dropped from the Missouri River Import to Red River Valley alternative, thus eliminating open water conveyance of treated Missouri River water for that alternative. Additionally, the volume of water imported; hence, pipeline diameters required by Action Alternatives characterized in the DEIS, differ from that originally proposed. These changes and the potential for additional modifications to alternatives (e.g., incorporation of sand filtration or dissolved air flotation) may also be incorporated in Supplemental Draft Environmental Impact Statement (SDEIS)[1], but will not be fully addressed in this failure and consequence analysis, given the limits of scope and time that guide USGS in this technical support effort.

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[1]US Bureau of Reclamation (Reclamation) and Garrison Diversion Conservancy District, 2006, Supplemental Draft Environmental Impact Statement, Red River Valley Water Supply Project, North Dakota Great Plains Region by US Department of the Interior Bureau of Reclamation Dakotas Area Office, Bismarck, North Dakota.

This third-in-the-series report considers a preliminary evaluation of the role of failures in infrastructure (e.g., biota treatment and water transmission systems) as those influence biota transfer risks potentially associated with interbasin water diversions. Here, we summarize technical findings of CERC staff and their Department of the Interior (DOI) partners in the National Park Service (NPS). Section 1 provides an overview of the report, including background information regarding the Action Alternatives involving interbasin water transfers. Section 2 and its supporting Appendix 1 summarizes the technical approaches applied to the preliminary failure analysis and the evaluation of economic consequences using habitat equivalency analysis. Section 3 details the technical findings regarding infrastructural failures potentially resulting in biota transfer events and summarizes the risks of failure both numerically and categorically within spatial and temporal contexts. These failures are placed into ecological context in Section 4, which provides an ecological characterization of the area of concern, largely the Upper Missouri River and Red River basins of North Dakota, Minnesota, and Manitoba. Section 5 provides an analysis of economic consequences associated with biota transfers potentially linked to infrastructural failures, with a particular focus on the Sheyenne River and Lake Ashtabula. Appendix 2 and Appendix 3 support the HEA summarized in Section 5. Section 5 also provides a landscape perspective to this economic consequence analysis for the Sheyenne River and Lake Ashtabula through a comparison of the economic consequences of biota transfers for the Red River and Lake Winnipeg, Red Lakes River and Red Lakes, and the Sheyenne River and Lake Ashtabula. Section 6 is focused on a preliminary integration of the failure analysis and infrastructure failures may be viewed within the context of HEA outcomes detailed in Section 5. Section 7 provides a summary of risks and economic consequences, including a characterization of the uncertainties associated with the analysis. Section 8 provides literature cited and a partial bibliography supporting the report.

1.1 Source Water, Disinfection, and Treatment Options Considered in the Draft Environmental Impact Statement (DEIS)

In a manner consistent with the risk reduction analysis summarized in USGS (2005b), preliminary analysis of infrastructural failure considered two general attributes of the transmission system—the spatial attribute, or "where source water will be gained" to address Red River Valley water needs, and the implementation attribute, or "how the water will be delivered" to the Red River Valley from Missouri River sources (Figure 1-1).

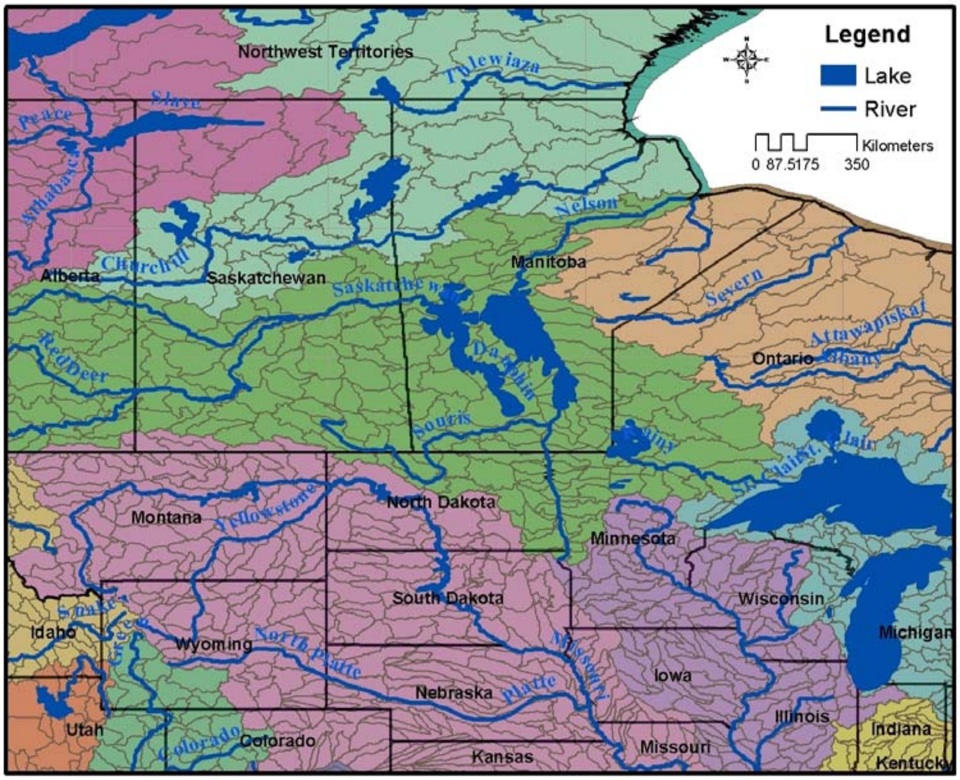

Figure 1-1. Basins of the Upper Missouri River (light purple), Upper Mississippi River (dark purple), Great Lakes (light blue), and Nelson River basin, including Red River basin (green).

As noted in USGS (2005b), eight alternatives considered in the DEIS reflected spatial attributes of water source differently. Seven alternatives were categorized spatially as in-basin or not in-basin action alternatives; one No-Action Alternative has been included in the DEIS, as required under National Environmental Policy Act (NEPA) of 1969 as amended ([Pub. L. 91-190, 42 U.S.C. 4321-4347, January 1, 1970, as amended by Pub. L. 94-52, July 3, 1975, Pub. L. 94-83, August 9, 1975, and Pub. L. 97-258, §4(b), Sept. 13, 1982)] 40 CFR Section 1502.14(d); see Table 1-1; see also Reclamation 2005a,c). A No-Action Alternative serves as a point of reference for evaluating action alternatives posited in the evaluation. Six alternatives focused on supplementing existing water supplies with in-basin or imported water (supplemental alternatives). Another proposed replacing all existing water supplies with Missouri River water (replacement alternative). Each of these no action, supplemental, and replacement alternatives are briefly characterized in the following section. For a more complete presentation of alternatives refer to DEIS and SDEIS (Reclamation 2006, 2005a).

1.1.1 No-Action Alternative. The No-Action Alternative considers the future without the project and provides a point of reference for evaluating action alternatives. No-Action Alternative includes all planned or reasonably foreseeable federal, state, tribal and local water supply projects that could be constructed in the Red River Valley by 2050 (see Reclamation, 2005a,c), and focuses on the counties of eastern North Dakota plus the Minnesota cities of East Grand Forks, Moorhead, and Breckenridge as the service area for all alternatives (Figure 1-2). Evaluation of system failure as it relates to biota transfers resulting from interbasin water diversions benefit from a consideration of risks captured by the No-Action Alternative.

Under a No-Action Alternative water sources consist of Red River, Sheyenne River, and tributaries, with Lake Ashtabula serving as reservoir storage and as primary water supply source. Existing groundwater sources would continue to be used as water supply, with presently untapped in-basin water supplies serving as groundwater sources for small communities and rural water systems. Purchase of groundwater and surface water irrigation rights would also serve water needs, where feasible.

Costs of infrastructure were not considered in this analysis. Rather, a detailed engineering cost analysis should be incorporated into the full design and specification process once an alternative is selected to meet the water demands of the Red River Valley as projected to 2050.

Table 1-1. Summary of in-basin and not in-basin alternatives identified and characterized in the DEIS.

Alternative		Brief Description
Water sources within Red River basin	No-Action (Section 1.2.1)	Red River Valley Water Supply Project is not realized
	North Dakota In-basin (Section 1.2.2)	Water sources primarily within Red River Valley of North Dakota
	Red River Basin only (Section 1.2.2)	Water sources rely on available surface water and groundwater from Red River Basin of Minnesota and North Dakota
	Lake of the Woods (Section 1.2.2, Figure 1-3)	Additional water sources from Lake of the Woods, Minnesota
Water sources from Missouri River basin	Import Missouri River waters via Garrison Diversion Unit (GDU) to Sheyenne River (Section 1.2.3, Figure 1-4)	Links GDU Principal Supply Works (Snake Creek Pumping Plant, Lake Sakakawea, Audubon Lake, and McClusky Canal) to Sheyenne River via pipeline
	GDU import pipeline (Section 1.2.3, Figure 1-5)	GDU Principal Supply Works and pipeline would convey Missouri River waters to Red River Valley
	Missouri River import to Red River Valley (Section 1.2.3, Figure 1-6)	Missouri River waters conveyed to Red River Valley via pipeline without relying on GDU supply works
	GDU water supply replacement pipeline (Section 1.2.3, Figure 1-7)	Missouri River waters conveyed to Red River Valley via pipeline

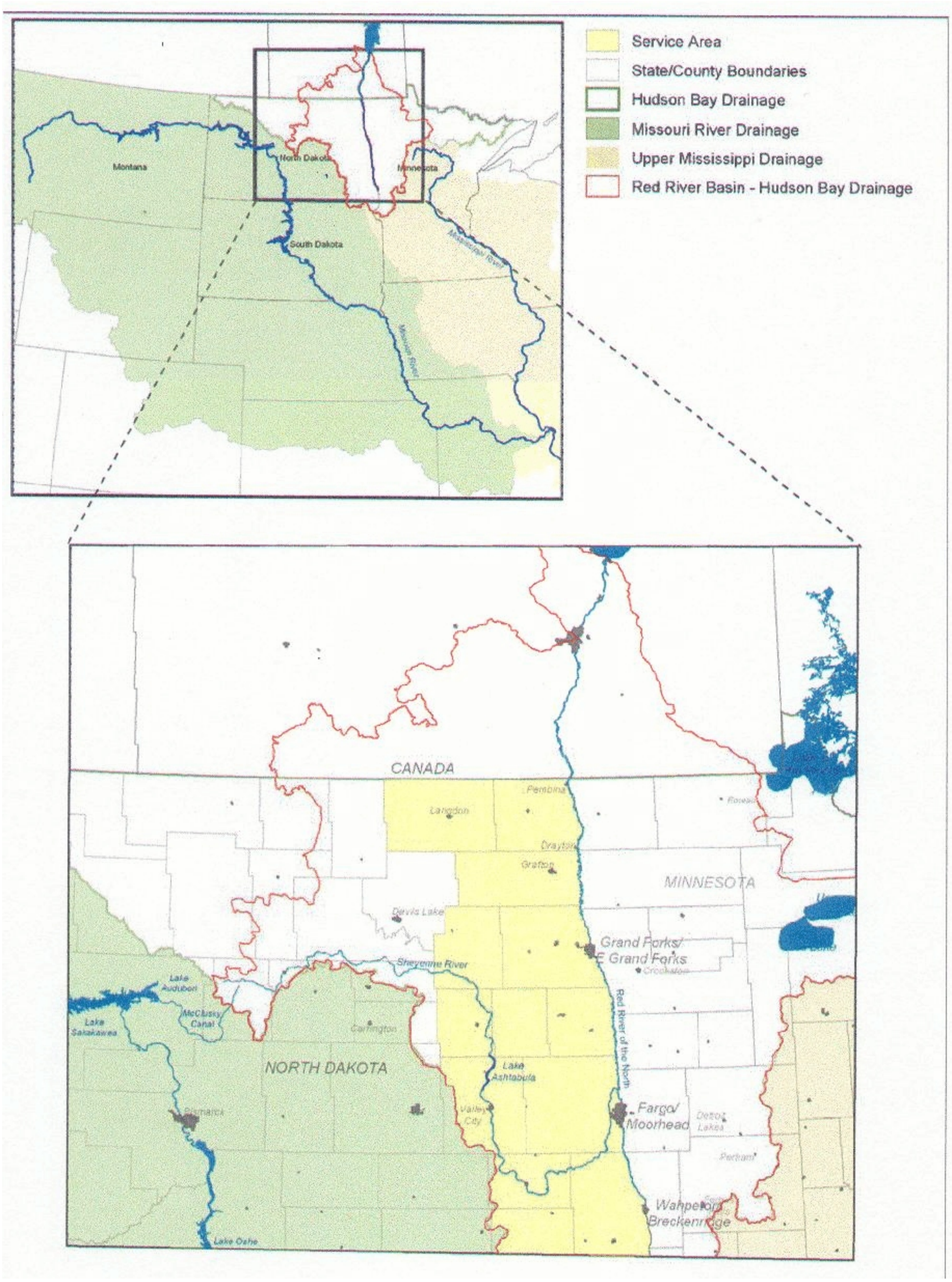

Figure 1-2. Area of potential effects and service area of the Red River Valley Water Supply Project (Service area in yellow and area of potential effects within black box; Source: DEIS).

1.1.1.1 Risk Reduction and No-Action Alternatives. The No-Action Alternative is an in-basin alternative that does not consider supplementing the water supply to the Red River Valley. Although "no action" is specified in this alternative, the DEIS recognizes that water management options within the Red River basin will be pursued between now and 2050. These management options, however, do not include designed interbasin water diversions completed under a federal project. Under the No-Action Alternative, risks of interbasin biota transfers *directly* linked to designed water diversions between Missouri River and Red River basins would be practically zero, because constructed pathways linking Missouri River and Red River basins would not be completed under a federally engineered water diversion. Risks of interbasin biota transfers and species invasions would not be eliminated, however. Competing pathways associated with stochastic environmental events (e.g., floods, seasonal storms) that are relatively independent of engineered infrastructure required to satisfy water demands under the No-Action Alternative may continue to yield biota exchange between Missouri River and Red River basins, as past paleoecological accounts (see Appendix 18; USGS 2005a), recent flood events (e.g., http://www.crh.noaa.gov/mbrfc/ flood.htm; http://edc.usgs.gov/sast/; Interagency Floodplain Management Review Committee 1994), and real-time monitoring and empirically-based prediction might suggest (e.g., http://water.usgs.gov/cgi-bin/dailyMainW?state= us&map_type=flood&web_type=map; Li and Simonovic 2002). Similarly, anthropogenic-dependent mechanisms not associated with Action Alternatives might alter biota exchange between Red River and Missouri River basins (see Kerr et al 2005; Taylor and Irwin 2004; Maki and Galtowitsch 2004 for recent publications discussing other pathways enabling biota transfers or species invasions).

1.1.2 In-basin Action Alternatives. **North Dakota In-Basin Alternative.** As noted in USGS (2005b), one of six supplemental water alternatives among the Action Alternatives, the North Dakota in-basin alternative primarily uses the Red River and other North Dakota water sources to meet future water demands of Red River Valley. No engineered interbasin water diversions are included in this alternative. A pipeline would capture Red River flows downstream of Grand Forks and recirculate flows back to Lake Ashtabula to meet Municipal, Rural and Industrial (MR&I) water demands. This alternative would also include developing new groundwater sources in southeastern North Dakota and purchasing existing irrigation water rights in the Elk Valley Aquifer. Under this alternative, aquifer storage and recovery (ASR) systems are proposed for Fargo, West Fargo, and Moorhead, Minnesota. Moorhead, Minnesota would also continue to draw on Minnesota groundwater sources to supplement its water supply. Although additional storage reservoirs would be needed by communities in the northern end of Red River

Valley under this alternative, the extent and type of storage (e.g., storage for raw or treated waters) would require specification in the future.

Red River Basin Alternative. In contrast to the North Dakota in-basin alternative, the Red River basin alternative would supplement water supplies by drawing on a combination of the Red River, other North Dakota water sources, and Minnesota groundwater. No interbasin water diversions are included in this alternative. A series of well fields would be developed in Minnesota with an interconnecting conveyance pipeline serving the Fargo-Moorhead metropolitan area. This alternative would rely on the existing storage and regulation capability of Lake Ashtabula to manage flows in the Sheyenne River, and would include the same North Dakota and Moorhead groundwater features as in the North Dakota in-basin alternative. Again, although additional storage reservoirs would be needed by communities in the northern end of Red River Valley under this alternative, the extent and type of storage (e.g., storage for raw or treated waters) would require specification in the future.

Lake of the Woods Alternative. This supplemental alternative would use a combination of North Dakota and Minnesota water sources to meet the future water demands of the Red River Valley (Figure 1-3). While water diversions from Lake of the Woods to Red River Valley require transfer of water from one sub-basin to another sub-basin within the HUC[2]09, no interbasin water transfer between Missouri River and Red River basins is included in this alternative. The primary feature would be a pipeline from Lake of the Woods to the major population centers of the Red River Valley. As with the previous alternative, this alternative relies on the existing storage and regulation capability of Lake Ashtabula. It would include the same North Dakota and Moorhead, Minnesota groundwater features as the North Dakota In-Basin Alternative. Additional storage reservoirs would be needed by communities in the northern end of the valley.

[2] HUC = hydrological unit code

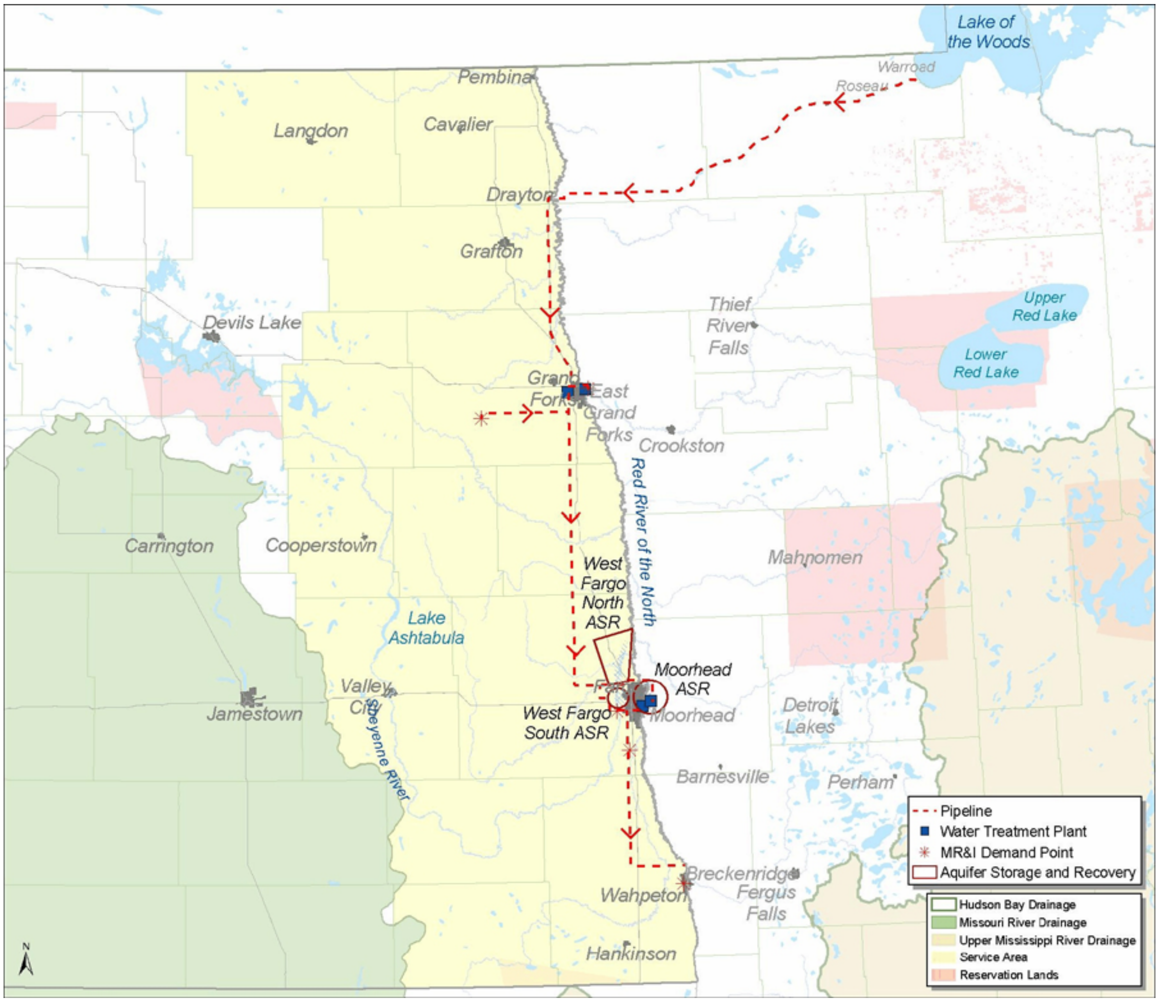

Figure 1-3. Lake of the Woods alternative (relative locations; scale not included)

1.1.2.1 Risk Reduction and In-basin Action Alternatives. Under any of these in-basin alternatives—North Dakota in-basin alternative, Red River basin alternative, or Lake of the Woods alternative—risks of interbasin biota transfers arising from water diversions between Missouri River and Red River basins *directly* linked to interbasin water diversions would be practically zero. As with a No-Action Alternative, in the absence of infrastructure needed to implement an interbasin water diversion, pathways directly linking Missouri River and Red River basins would not be completed under these alternatives. However, risks of biota transfers and species invasions associated with biota exchanges between Missouri River and Red River basins would not be eliminated. For example, in addition to biota transfers associated with competing stochastic environmental events (e.g., floods and seasonal weather extremes), construction-related activities associated with any of the proposed projects would yield transient or permanent disruption to habitats in the area of concern, and these disruptions may directly or indirectly result in completed pathways and enable biota exchange between Missouri River and Red River basins. For example, construction-related activities could increase disturbance habitat in upland or riparian areas, and the likelihood of propagules (e.g., vehicle-associated transport of terrestrial or aquatic biota, wind-aided dispersal of plant seeds to disturbance habitats) gaining access to previously unoccupied habitat may be increased, depending on the type and extent of those construction activities. Secondary effects could also indirectly promote biota transfers, enhance species invasions, and altered metapopulation dynamics in the area of concern, although effects would be indirectly related to management actions to address water needs of the valley. Project-specific activities would be characterized as being contributory factors in the biota exchange process (see USGS 2005a, particularly Section 4 and uncertainty analysis).

While the Lake of the Woods alternative represents a water diversion within HUC09, proposed water transfers would occur between sub-basins within HUC09 and may pose risks associated with the dispersal and expanded distribution of biota of concern presently in HUC0903 (e.g., Lake of the Woods occurs in 09030009) to HUC0902 (e.g., Upper Red River occurs in 09020104) through water transfers envisioned as part of this Lake of the Woods alternative. Past experience, e.g., rainbow smelt invasion of Lake of the Woods, would suggest that close proximity to Great Lake basin (HUC04) or other source areas might enable or promote continued biota transfers from that basin to sub-basins within HUC09 and areas immediately adjacent in HUC10 (see Appendix 7, USGS 2005a). Although intrabasin water diversions were not considered in USGS (2005a) as part of their biota transfer analysis, the transfer of water between sub-basins may warrant consideration as far as enabling or promoting existing pathways of transfer from Great Lakes and Hudson Bay basins to both Red River and Missouri River basins. Although not an interbasin water transfer between 2-digit HUCs, the proposed action alternative transferring source waters from Lake of the Woods does reflect a transfer of source waters between sub-basins, and approximately 265 miles of pipeline would be involved in that transfer. As a source area, the Great Lakes basin provides a rich source of non-indigenous species that were originally invasive within the system, have become established, and could serve as founders in a stepwise progression of species expansion from the Great Lakes westward to the Red River and subsequently the Missouri River basins (see USGS 2005a).

1.1.3 Action Alternatives Relying on Source Waters from Missouri River. **Garrison Diversion Unit (GDU) Import to Sheyenne River Alternative.** This alternative would supplement existing water supplies to meet future water needs with a combination of the Red River, other North Dakota in-basin sources, and import Missouri River water (Figure 1-4). An intake pumping plant located on McClusky Canal would rely on a conventional wet-sump

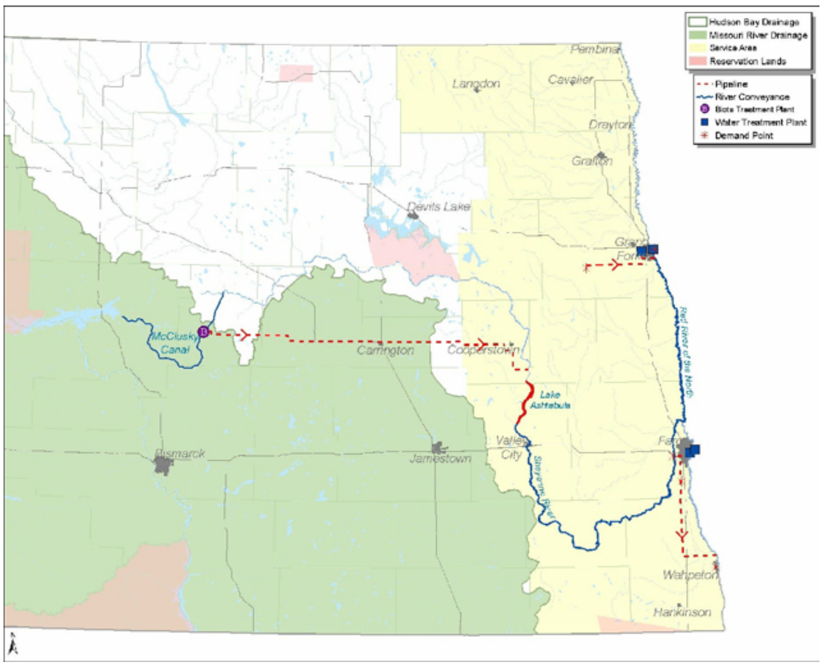

Figure 1-4. GDU Import to Sheyenne River Alternative (relative locations; scale not included).

pumping station, and the principal conveyance feature would be a pipeline from the McClusky Canal to the Sheyenne River about 3 miles (approximately 4.8 km) above Lake Ashtabula where treated Missouri River water would be released. The pipe would be sized so peak-day demands could subsequently be met by Lake Ashtabula releases into the Sheyenne River, and in the conceptual design pipe size varies from 50 to 56 inch diameter pipe to 60 to 66 inch diameter pipe,[3] depending on hydraulic design and volume of water being delivered to receiving stations (see Section 3 for pipe miles; see also Reclamation 2005). This alternative would include a biota treatment plant at the intake located at McClusky Canal and a pipeline to serve industrial water

[3] Common pipe sizes used in the transport of large quantities of municipal, rural and industrial (MR&I) water are typically manufactured in increments of foot and half of a foot (e.g., 48 and 54-inches). Pipe diameters used throughout this analysis reflect slightly oversized pipe listed in early cost estimates.

demands in southeastern North Dakota. The biota treatment process would use coagulation, flocculation, sedimentation, and ultraviolet disinfection (Table 1-2).

GDU Import Pipeline Alternative. This alternative would supplement existing water supplies to meet future water needs by conveying water from the Missouri River via the McClusky Canal and a pipeline to the Red River Valley (Figure 1-5). An intake pumping plant located on

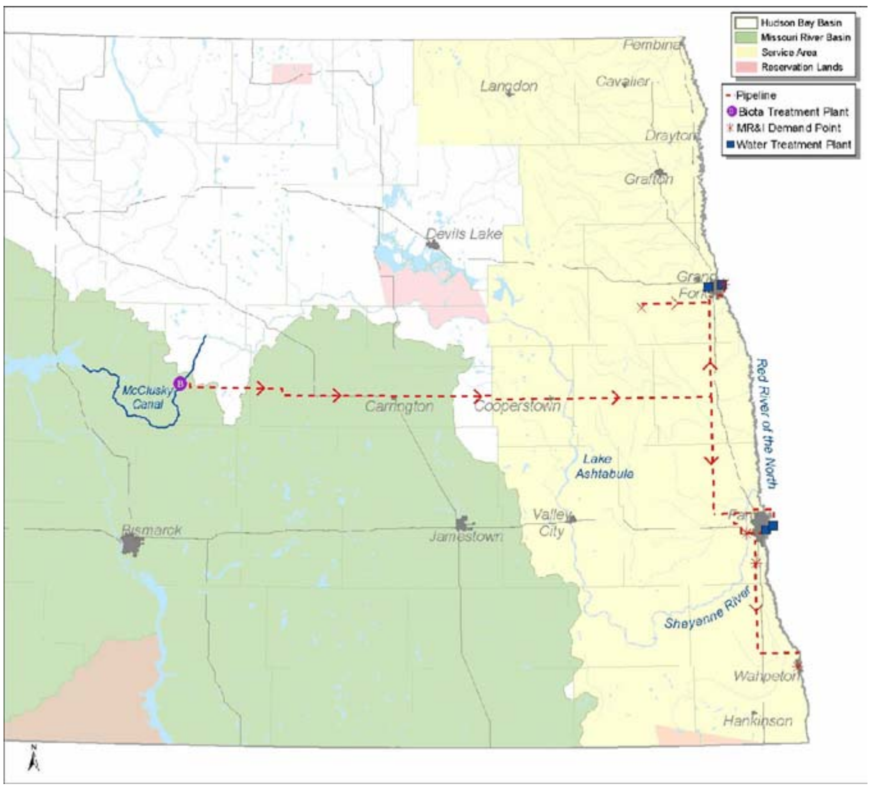

Figure 1-5. GDU Import Pipeline Alternative (relative locations; scale not included).

McClusky Canal would rely on a conventional wet-sump pumping station, and the principal conveyance feature of the alternative would be a pipeline from McClusky Canal to the Fargo and Grand Forks metropolitan areas sized to meet peak-day shortages (see Section 3 for range of pipe sizes and miles; see also Reclamation 2005). The alternative includes a biota treatment plant at the McClusky Canal and a pipeline to serve industrial water demands in southeastern North Dakota, and would rely on existing storage and regulation capability of Lake Ashtabula in addition to water input derived from Missouri River sources to meet downstream MR&I water demands. The biota treatment process would use coagulation, flocculation, sedimentation, and ultraviolet disinfection (Table 1-2).

Missouri River Import to Red River Valley Alternative. This alternative would supplement existing water supplies to meet future water needs by conveying treated water in a pipeline from the Missouri River south of Bismarck directly to Fargo and Grand Forks (Figure 1-6). The alternative would rely on a radial collector well system for extraction of source water from Missouri River alluvial deposits and includes a biota treatment plant at the Missouri River

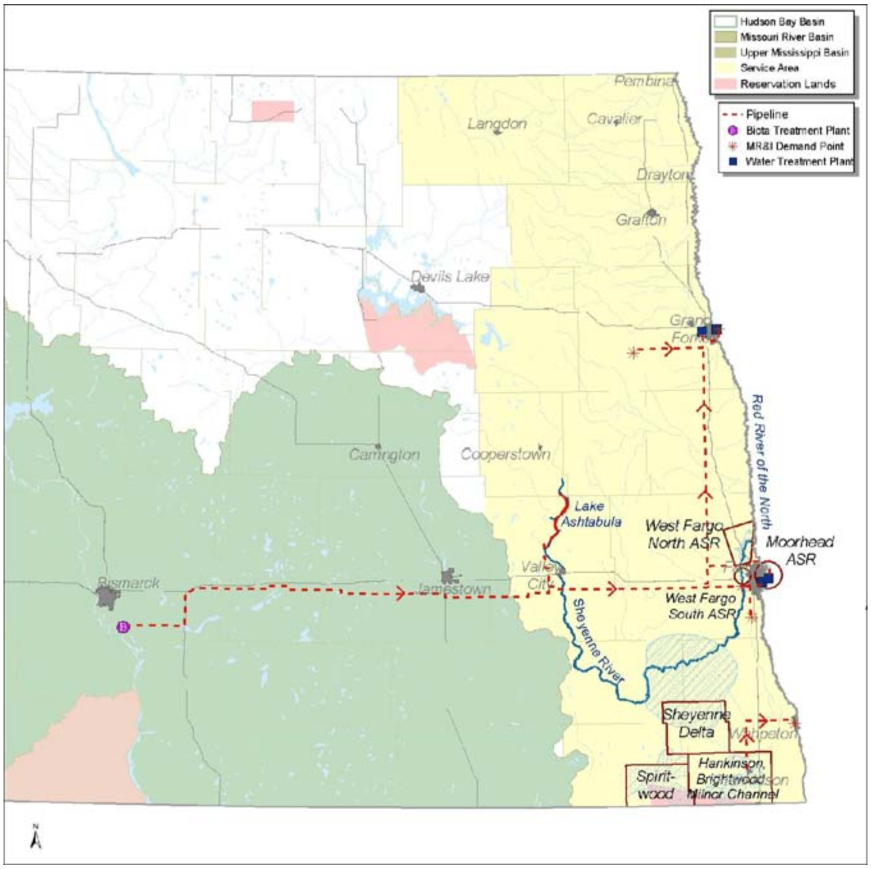

Figure 1-6. Missouri River Import to Red River Valley Alternative (relative locations; scale not included).

near Bismarck (Reclamation 2005b,c). The biota treatment process would use coagulation, flocculation, sedimentation, and ultraviolet disinfection (Table 1-2). The size of the pipeline would be optimized by including a spur pipeline to release treated Missouri River water into Lake Ashtabula that would act as a regulating reservoir (see Section 3 for summary of pipe sizes and miles; see also Reclamation 2005). The alternative would include the same North Dakota and Moorhead groundwater features as the North Dakota In-Basin Alternative. Communities in the northern end of the valley would need additional storage reservoirs.

GDU Replacement Water Supply Pipeline Alternative. Unlike the previous water supply alternatives that propose to supplement existing water supplies, this alternative would use water imported from the Missouri River to replace all other MR&I water supplies in the service area to meet future water demands. As with other alternatives located on McClusky Canal for source water intake, this alternative would rely on a conventional wet-sump pumping station to relay source waters to a nearby biota-water treatment plant. The principal conveyance feature of the alternative would be a pipeline from the McClusky Canal into the Red River Valley interconnecting most of the cities, rural water systems, and industries (Figure 1-7). A few extreme northern and southern water systems would not be connected to the system, but the capacity to serve them in the future is provided for in the design. The conveyance pipeline would have a

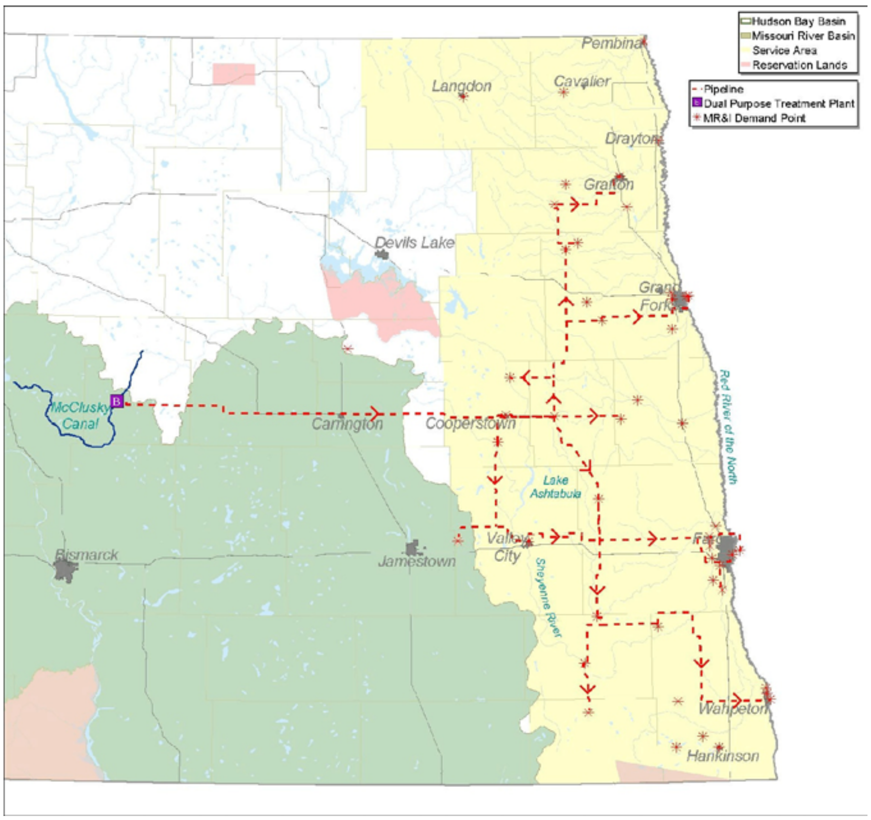

Figure 1-7. GDU Replacement Water Supply Pipeline Alternative. (relative locations; scale not included)

capacity to meet the peak-day water demand of the entire service area (see Section 3 for summary of pipe sizes and miles; see also Reclamation 2005). For this alternative, in addition to conventional pre-treatment and UV disinfection, the biota treatment plant at McClusky Canal would include lime softening and microfiltration to deliver water treated to Safe Drinking Water

Act (SDWA) standards to the Red River Valley. These measures are necessary, since numerous water systems in the valley use groundwater and lack the capability to treat surface water. Hence, treated water must be supplied to these systems or they would have to adapt their current groundwater water treatment plant to treat surface water. The entire service area would receive bulk-treated water in this alternative (Table 1-2).

Table 1-2. Summary of action alternatives involving imports of source waters to Red River basin from the Missouri River basin*

Water import alternative	Approximate pipeline in transfer conveyance (miles)	Biota treatment plant location	Summary of water processing incorporated into proposed biota treatment plant**						
			Coagulation	Flocculation	Sedimentation	UV treatment	Chlorine treatment	Lime softening	Microfiltration
GDU Import to Sheyenne River	130	at McClusky Canal	✔	✔	✔	✔	✔		
GDU Import Pipeline	260	at McClusky Canal	✔	✔	✔	✔	✔		
Missouri River Import to Red River Valley	300	at the Missouri River	✔	✔	✔	✔	✔		
GDU Water Supply Replacement Pipeline	600	at McClusky Canal	✔	✔	✔	✔	✔	✔	✔

* based on Draft Report on Red River Valley Water Needs and Options (Reclamation, 2005a); Water Treatment Plant for Biota Removal and Inactivation, Preliminary Design and Cost Estimates – Draft Report, Red River Valley Water Supply Project, North Dakota, Great Plains Region (Reclamation, 2005b); DEIS (Reclamation, 2005c).

** "✔" indicates treatment process included in proposed design.

1.1.3.1 Water Treatment Technologies Proposed In Action Alternatives and Their Potential to Reduce Risks Associated With Biota Transfer. As noted in USGS (2005a), water diversions envisioned and originally proposed over 60 years ago under the Flood Control Act of 1944 differ markedly from those currently being considered by Reclamation (2005a) as water management options. Given the concerns related to biota transfers initially voiced by the International Joint Commission (IJC) in the 1970's, control systems posited in these alternatives reduce risks of biota transfers potentially associated with water diversions between Missouri River source waters and the receiving system, Red River of the North. Whether that risk reduction is sufficient to stakeholders' risk tolerance remains a risk management decision that is not considered in this technical report. There are no regulatory benchmarks specific to biota transfers nor promulgated standards specifying "acceptable risks" related to species invasions. Implementing interbasin water transfers in compliance with control systems proposed in the DEIS would bring to resource management discussions a system of control technologies that are risk reduction tools for managing potential biota transfers. While these tools serve to reduce risks—in this case risks related to biota transfers—there are attendant uncertainties that must also be considered as noted in USGS (2005a) and characterized in Section 7 of this report.

1.2 Project trajectory and beyond

Work completed in this preliminary failure and consequence analysis anticipate more detailed engineering design and cost analysis, once the alternative of choice is selected. This report specifically addresses a preliminary analysis of infrastructure failures that may adversely affect water treatment and water transmission functions of the control system envisioned for interbasin transfer of source waters from the Missouri River to receiving areas in the Red River basin. Risk-related outcomes identified in this analysis may also provide preemptive evaluations of in-basin alternatives, if one of those are selected as alternative of choice. For example, construction activities and their potential roles in mediating biota transfers must not be undervalued, e.g., disturbance habitats may enable invasions by terrestrial plant propagules otherwise precluded from establishing sustainable populations in previously intact terrestrial habitats along the pipeline right-of-way. Additionally, while the focus of this report lies on system failures that might enable biota transfers through biota treatment and pipeline failures, other control system failures are briefly considered that could reduce invasion risks to practically zero. For example, pump failures associated with water intakes may well disable water delivery, effectively reducing water imports for some period of time. In a time-conditioned analysis, these unintended disruptions in service could reduce risks of biota transfer, since movement of water from one basin to the other might be suspended. Yet, this time-dependent event may foreshadow heightened future risks, given the hydraulic realities of pressure transients and increased risks of pipe bursts in a corrosion-aged water transmission system.

Clearly, the number of scenarios potentially played out in evaluating risks associated with biota transfers realized as collateral events to water diversions from the Missouri River to the Red River basin far exceeds the specification currently available for the preliminary analyses that follow. The failure and consequence analysis that follows, however, provides a level of effort consistent with the intent of the DEIS (Reclamation 2005), which acknowledges the early stage of engineering design, and Reclamation's decision to opt out of alternative-of-choice selection. Similarly, the failure and consequence analysis summarized herein does not identify one alternative as being better than another. Rather, the primary objective of this failure and consequence analysis centers on the role that technical evaluations play in risk assessment process, as noted in USGS (2005a) and other guidance available to the tasks facing natural resource managers (see Section 1, USGS 2005a). Action Alternatives are evaluated numerically and categorically, and extend the evaluation of risk reduction characterized in USGS (2005b). Through these numerical and categorical rankings, stakeholders and their representative risk managers may be served with technical support that argues for their selection of an alternative of choice among those No-Action or Action Alternatives identified in the DEIS (Reclamation 2005), or just as likely, leads to revised options for meeting the water needs of populations in the Red River Valley to 2050.

2.0 Background and Specification of Tools Used for an Initial Evaluation of System Failure and its Potential to Influence Risks of Biota Transfer

While a comprehensive review of the tools used in this failure analysis is not necessary to the management of risks, a brief background on the literature and data search completed to support this analysis opens this section, then followed by an extended overview of survival and reliability analysis as that relates to the current evaluation of control systems (e.g., water treatment and transmission system) identified in the DEIS (Reclamation 2005). The failure analysis reported herein directly extends the risk reduction analysis summarized in USGS (2005b). Consequence analysis for the Sheyenne River and Lake Ashtabula, as derived from a HEA, has been characterized in detail in previous reports (USGS 2005a,b). Here, HEA is briefly summarized as one of the tools applied to the current investigation, then subsequently detailed in Section 5. HEA is also revisited in Section 6 which details the outcomes of this investigation on control system failures relative to the HEA process completed for the Sheyenne River and Lake Ashtabula. For a more extensive treatment of any of the analytical tools discussed in this section, the reader is referred to Appendix 1 and the references included therein and in Section 8, as well as earlier reports in this series (USGS 2005a,b).

2.1 Literature Search and Collection of Existing Failure Data and Information Regarding Water Transmission Systems

Existing failure rate data was available from a variety of sources, the most common sources including:

- Historical data about the device or system under consideration.
- Many organizations maintain internal databases of failure information on the devices or systems that they produce, which can be used to calculate failure rates for those devices or systems. For new devices or systems, the historical data for similar devices or systems can be useful and serve as a initial estimate.
- Government and commercial failure rate data.
- Handbooks of failure rate data for various components are available from government and commercial sources. Several failure rate data sources are available commercially that focus on commercial components, including
    - The T-book (Nordic Nuclear Power Plants)

- Spanish database for reliability data collection and Maintenance Rule implementation (BDATA)
- Offshore Reliability Data (OREDA), as accessed through OREDA (2002); see also http://www.dnv.com/technologyservices/handbooks/index.asp
- Guidelines for Process Equipment Reliability Data, Center for Chemical Process Safety of the American Institute of Chemical Engineers
- Reliability Data, Centralized Data Base (ZEDB), Germany
- IEEE Guide To The Collection And Presentation Of Electrical, Electronic, Sensing Component, And Mechanical Equipment Reliability Data For Nuclear Power Generating Stations, Published by the Institute of Electrical and Electronics Engineers, Inc.
- OECD on its behalf is setting up a database relative to the failure of digital I&C namely Computer-Based Systems Database (COMPSIS)
- Common-Cause Failure Database and Analysis System developed by USNRC and INEEL (NUREG/CR-6268)
- International Common Cause Data Exchange (ICDE) by SKI, USNRC and OECD
- NUREG/CR-5497

- Field and Laboratory Testing. The most accurate source of data is to test samples of the actual devices or systems in order to generate failure data. This is often prohibitively expensive or impractical, so that the previous data sources are often used instead.

For the literature search supporting the failure analysis, the main literature database providers included Cambridge Scientific Abstracts (CSA) and OCLC FirstSearch. Databases searched in CSA included Environmental Sciences and Pollution Management, Water Resources Abstracts, GeoRef, and Conference Papers Index. Databases in OCLC FirstSearch searched included Agricola, ArticleFirst, BasicBiosis, Dissertations, GeoBase, and WorldCat. BioAgIndex, Electronic Collections Online, PapersFirst, and Proceedings. Ingenta database provider was also used for some searches. Focused database searches of American Society of Civil Engineers (ASCE), American Society of Mechanical Engineers (ASME), and National Research Council Canada-Institute for Research in Construction (http://irc.nrc-cnrc.gc.ca/index_e.html) libraries provided data sources for analysis of water system infrastructure and its components.

Search terms. Beyond data available through compilations from government and industry sources, searches for failure data for the conceptual designs advanced in the DEIS for the biota treatment and water transmission system suggested search terms and data sources such as

American Water Works Association (AWWA), ASCE, and ASME. In addition to professional associations such as these, collaborative government-industry sources (e.g., joint EPA-AWWA publications; see Section 8) were tapped to acquire quality data that characterized, e.g., failure rates for water treatment processes such as UV disinfection and microfiltration, mechanical failure rates for pumps, valves, and gates, and pipe of different materials (such as ductile iron, steel, and polyvinylchloride). Depending on the quantity of citations or data compilations discovered, reiterated searches were completed using search terms to discriminate among available data sources, e.g., distinguish between failure rates for different types of pipelines.

Search outcomes. Existing literature and data collected from the literature search reflected both observational and experimental data, with much of the observational data acquired consequent to field studies focused on water distribution systems and evaluations of these system's reliability.

2.2 Background on Failure Analysis

Complex interactive systems, be those engineered systems designed and constructed following industry standards or biological systems at any level of organization (e.g., molecular, cellular, tissues and organs, organismic, populations, communities, or ecosystems), are subject to inevitable events commonly referred to as "failures." These failures potentially compromise the system's performance for various time periods, ranging from the inconsequential events to catastrophic terminal events. Failure analysis, especially within the context of biological systems and their relationships to alternative engineering systems, was a primary tool in the evaluation of risks of biota transfers associated with water diversions between the Missouri River and Red River basin (USGS 2005a).

Although failures range from the inconsequential to the catastrophic, from the point of view of assessing system reliability, catastrophic failures are handled no differently from failures that occur when a key parameter of a system of interdependent components drifts slightly out of specification. Regardless of the systems complexity, departures from nominal structure or function call for an unscheduled maintenance action or restoration and recovery process in engineered or ecological systems, respectively. Consequences associated with failure events vary widely, since the restoration of a system's performance is a function of magnitude of departure (e.g., more than one component fails) and the sensitivity of the system to failure of its various components (e.g., not all components may be equally sensitive to failure and some components may be more critical to system performance than others at various periods in a system's lifetime).

For the current investigation, infrastructure failures were considered the major concerns of Reclamation and Technical Team. From a system perspective, failures in transmission systems for moving water from the Missouri River to the Red River basin were considered critical to biota transfers (both species invasions and shifts in metapopulations). Such transfers were variably affected by alternative control systems incorporated into the water diversion's design in order to reduce risks. Failure analysis, then, was critical to the evaluation of risks, since the biological or ecological failures (e.g., a species invasion) associated with interbasin water transfers would be influenced by infrastructure failures in the alternative technologies proposed for control system linking Missouri River sources with importing areas in the Red River basin.

Extended background on failure analysis was incorporated into USGS (2005a) in Appendix 4 as summary derivatives of NIST/SEMATECH (2004), which serves as a starting point for this overview and Appendix 1 of this report. Appendix 1 presents a more detailed account of underlying concepts in failure analysis, and should be reviewed as needed to support the background material in this section. As noted in USGS (2005a,b), the roles of control system failure will be key to anticipating and minimizing risks and consequences of biota transfers potentially associated with interbasin water diversions between Missouri River and Red River basins. As such, future selection of control systems—water treatment and water transmission infrastructure—should reflect preliminary evaluations of system reliability, given the critical function of that the water treatment and water transmission control system in assuring that biota transfers do not occur in the process of water diversion. System failure could result in biota transfer, which could potentially contribute to establishment of invasive species or shifts in metapopulations of, e.g., disease agents cosmopolitan in their distribution across the northern Great Plains and Great Lakes basin. The present baseline failure analysis should provide an initial investment of time and effort into the hazard assessment-critical control process (HACCP). HACCP is a risk management tool commonly applied across a range of industrial and resource management issues, including the prevention and control of invasive species (USGS 2005a,b; see http://www.haccp-nrm.org/default.asp; FAO/WHO 1998, WHO 1997).

As a first iteration, failure of a control system may be characterized by "macro-rate constants" that reflect a composite of failure rates of non-repairable or repairable components of the control system, e.g., failures occurring immediately following start up may reflect malfunction associated with manufacturing defects, while system failures that occur years after start up may reflect failures in pipes associated with age-related corrosion. Data supporting the preliminary failure analysis conducted in this investigation were derived from a wide range of available data without distinction of manufacturer, e.g., of pumps, valves, or pipes. Once full engineering designs are available, higher resolution analysis based on component failure rates may be developed within a HACCP-type process, so risk management practices may be developed to minimize risks potentially associated with biota transfer.

Industry experience, e.g., failure rates observed for other systems, were used in the analysis, in part, as a starting point in the characterization of project baseline system behavior which might serve all stakeholders in managing risks inherent to any engineering system. As available, data from other Reclamation water treatment-water transmission projects were incorporated into the analysis of failure. If data are available for analysis, future analysis may rely on repair rate models based on cumulative failures over time, using HACCP to guide the analytical process. Alternative approaches may be used for modeling the rate of occurrence of failure incidences for a repairable system, provided data are available, and repair rate as "rate of failures per unit time" could also be characterized. Depending on data available to support this analysis, control systems were identified that present advantages over competing alternatives. The paradox of reliability analysis based on historic data is, the more reliable a water treatment and water transmission system is, the more difficult it is to compile failure data for the analysis. Hence, censored data and the lack of failures may influence the conservativeness of existing data. Uncertainties and the influence that uncertainty plays in selection of conservative assumptions in the analysis may influence future analysis, as engineering designs gain increased resolution.

Anticipating Primary Causes of Control System Failure. Regardless of the engineered system being evaluated, primary causes of system failure may be categorized as being linked to human factors, design or materials failures, extreme conditions or environments, and most commonly, combinations of these reasons (e.g., Table 2-1 lists factors related to pipe failure; see also USGS 2005b). In evaluating natural hazards and failures of natural systems through time, analogous factors may be characterized, most of which are subject to age-related changes in the system or more likely, age-related changes in system components. The failure analysis detailed in Section 3 of this report focuses on Action Alternatives summarized in the DEIS. Potential interaction between engineered control systems and natural resources, e.g, Missouri River, Sheyenne River, or other landscape features, will be considered primarily as part of the uncertainty analysis linked to preliminary failure analysis of Action Alternatives (see Section 7).

Table 2-1 General listing of concerns related to failure analysis for buried pipelines (adapted from EPRI 2001).

Time-dependent Attributes	**Time-independent Attributes**	**Materials Attributes**
External Corrosion (soil interactions with pipe exterior)	Mechanical Damage	Manufacturing Related
• General corrosion	• Outside party (e.g., other vendors)	• Defective Pipe Seam
• Localized corrosion (pitting, crevice, and intergranular attack)	• Installation	• Defective Pipe
• Microbiologically-influenced corrosion	• Previously damaged	• Wrinkle bend or buckle
• Galvanic corrosion		• Stripped threads/coupling failure
• Environmentally-assisted cracking and corrosion fatigue	Incorrect Operations	
• Stray current	• Operator error	Welding Fabrication Related
	• Incorrect operating procedure	• Defective pipe girth weld
Internal Corrosion (water interactions with pipe interior)	• Over pressurization (potentially yielding pressure surge, e.g., upon correction)	• Defective long seam weld
• General corrosion		
• Localized corrosion (pitting, crevice, and intergranular attack)		Equipment
• Dealloying		• Gasket O-ring
• Microbiologically-influenced corrosion	Outside Force	• Control/relief equipment malfunctions
• Galvanic corrosion	• Earth movements	• Seal/pump packing failure
• Environmentally-assisted cracking and corrosion fatigue	• Heavy rain, floods	• Miscellaneous
Fatigue (pipe material aging)		
• Pressure cycling (with associated pressure surges)		
• Thermal cycling		
Heavy fouling/clogging (deposition on pipe inner walls)		

2.3 Preliminary Reliability Analysis and the Evaluation of Biota Treatment and Water Transmission Failures

In its simplest statement, the statistical discipline referred to as survival analysis deals with end-of-life events in biological systems and failure in mechanical systems. For our current focus on the evaluation of infrastructure failures in interbasin water transfer systems, the analysis approaches engineering topics referred to as reliability analysis, a tool undoubtedly incorporated into future efforts as engineering activities progress beyond the conceptual designs summarized in the DEIS (Reclamation 2005a). Death or dysfunction in biological systems and breakdowns or failures in mechanical systems or system components are considered “events” of concern in survival analysis. Much of the analysis completed in this preliminary analysis of infrastructural failure borrows from existing models of death or failure which are generically termed time-to-event models.

Mathematically, survival analysis considers a range of questions pertinent to the evaluation of events that occur during the “life history” of a system regardless of whether that is a biological system at any particular level of organization (e.g., an individual organisms or a population of organisms) or a water treatment and transmission system intended to disinfect source waters prior to its export via pipeline to another area some distance from source waters. For example, the current investigation’s primary focus has been, “what is the failure rate of biota treatment and water transmission systems as envisioned in conceptual designs for an interbasin water diversion as summarized in the DEIS?” Even in a conceptual design, preliminary analysis of infrastructure failure should benefit natural resource managers and environmental decision-makers regarding the system’s characteristics that would likely increase or decrease the odds of survival, or more pointedly, the odds that biota transfers would be realized in the event of control system failure.

Failure analysis applied to this preliminary evaluation reflects the underlying assumption of survival theory—failure occurs only once for each system. Recurring-event or repeated-event models for, e.g., repairable systems, relax that assumption, yet for biota transfers the “fails once” assumption may be sufficient. Although repeated trials in any biota transfer or species invasion are common to the dispersion and establishment of sustainable populations process (see USGS 2005a and references therein), it is possible that a single incursion may yield a successful outcome associated with a single system failure. Through time-in-service, these “one-time failures” may also be viewed as recurring events which are relevant in systems reliability. Regardless of the “fails once” or “repeated failures” assumptions necessary in the analysis, the current implementation of failure analysis reflects a long history of application to engineering systems evaluation, which is reflected in the brief background that follows and is necessary to follow the output generated and summarized in Section 3.

2.3.1 Reliability Analysis and Life Distributions. A variety of methods have been developed to support failure analysis, particularly when applied to risk reduction evaluation and risk management. Reliability theory developed apart from probability and statistics, yet its application to a range of engineering and natural resource management issues assures analysis commensurate with the available data (see, e.g., Tung et al. 2006, Pukite and Pukite 1998, Muhlbauer 2004, Kleiner et al. 2005, Grayman et al. 2001, Cromwell et al. 2002, Cesario 1995). For example, each of the control systems advanced in the DEIS as alternatives to achieve an interbasin water diversion are, at first glance, examples of "repairable systems" having a history that provides *a posteriori* estimates of failure rates or lifetime distributions, e.g., for components of the system that are non-repairable and fail over time. The reliability of any system reflects the reliability of its components. This building up to the system from the individual components will initially be considered in terms consistent with the design specifications, e.g., specific types of water treatment (e.g., pre-treatments followed by UV treatment or a membrane process) and specification of pipeline components such as type of pipe and its dimensions throughout the transmission system. Such a "bottom-up" method can be subsequently refined, if specifications change and as greater specification is gained through the project's development.

Appendix 1 includes background on the analytical tools applied to this preliminary analysis of system failure, especially as that relates to biota transfers. While conditioned on the conceptual designs currently identified in the DEIS (Reclamation 2005a), the preliminary forecasts characterized in this preliminary analysis may be refined by applying these analytical tools to more fully specified designs, wherein existing data more fully characterize the water treatment and water transmission functions of the control system. Much of the preliminary analysis completed in the current investigation is focused on graphic output typical of systems such as those identified in DEIS (Reclamation 2005a). While these results should be considered preliminary, they are sufficient to characterize differences among Action Alternatives reliant on interbasin water diversions. Depending on the risk tolerance of Reclamation and stakeholders, these preliminary forecasts may also be sufficient to eliminate alternatives from further consideration, identify alternatives warranting future consideration, or advance alternatives currently not captured by DEIS (Reclamation 2005a). Given the long history of graphic and quantitative analysis supporting reliability evaluations for water systems such as those advanced in the DEIS (Reclamation 2005a), the heuristic tools brought to the current analysis may serve future efforts to characterize risks of biota transfers linked to system failure. While numerically based on existing data and projections derived from Weibull analysis (see Appendix 1; see also Abernethy 2000, Murthy et al 2004, Reliasoft 2005a), the outcome projected in Section 3 is based on a simple scenario reflecting nominal system function throughout a 10,000-day lifetime. The graphic lifetime projection characterized in Section 3 is typical of many engineering systems (see, e.g., Abernethy 2000, Barlow 1998, Barlow and Proschan 1996, Blischke and Parbhakar Murthy 2000, Lawless 2003, Lee and Wang 2003, Meeker and Escobar 1998, O'Connor 2002, Rausand and Høyland 2004, Tung and Melching 2006) and biological systems (see Appendix 1; see also Petrovskii and Li 2006, Caswell 2001, Appendix 1, USGS 2005a).

2.3.2 Graphic representations of system lifetimes. Depending on the system, its design, and its components, various measures of system reliability may be characterized. Not surprisingly, the evaluation of system reliability is highly dependent on the system's design, its components, and its operations, which necessarily leads to the conclusion that no one "best method" for analysis exists, since the selection of the most suitable prediction method should be done based on, e.g., the water transmission system identified as the alternative of choice. For a preliminary analysis, however, opting to a familiar case could move risk management activities forward.

Since system failures and failure rate (ht(t) or λ) is time dependent, lifetime plots of system reliability are generally depicted by the idealized "bathtub curve" (Figure 2-1; see Appendix 1; see also USGS 2005a and references cited therein).

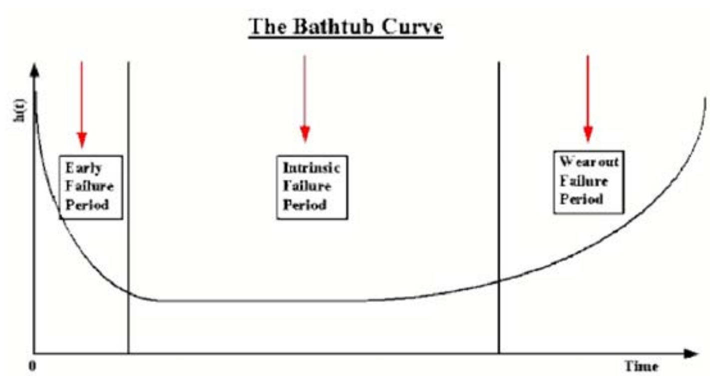

Figure 2-1. Ideal "bathtub curve" represents a hazard function characteristic of many system's lifetime distribution or hazard function (original figure modified from NIST source).

The bathtub curve is often modeled by a piecewise set of three hazard functions,

$$h(t) = \begin{cases} c_0 - c_1 t + \lambda, & 0 \le t \le c_0/c_1 \\ \lambda, & c_0/c_1 < t \le t_0 \\ c_2(t - t_0) + \lambda, & t_0 < t \end{cases}$$

While the bathtub curve is useful, not every product or system follows a bathtub curve hazard function (see Section 7).

2.3.3 Expression of failure rates used in this analysis. Failure rates are expressed as measures of time, but common engineering practice frequently relies on units of hours (or hours-in-service). Because failure rates may be relatively low, engineering notation often characterizes failures per million, or 10^{-6}, especially for individual system components. Under certain engineering assumptions, failure rates for complex systems are characterized as the sum of the individual failure rates of its components, as long as the units are consistent, e.g. failures per million hours.

2.4 Life-Cycle Assessment

The current analysis captures a snap shot of a conceptual system's lifetime that may well change before a final selection of alternative of choice, e.g., engineering designs will be develop, and eventually become final, wherein greater specification in design elements would support a more fully implemented engineering reliability analyses of the control system and its components. Within an interpretive context, the snap shot of system failures will be considered within a system's lifetime; in this particular investigation, an arbitrary 20- to 30-year span from date of initial start up through 10,000 calendar days. Given the early design attributes of the Action Alternatives optioned in the DEIS, the preliminary character of this investigation warrants a "life-cycle assessment" framework for the analysis, which may be more fully exploited once alternatives have been winnowed down by Reclamation and stakeholders.

Life-Cycle Assessment (LCA). Because of legislative and regulatory mandates such as National Environmental Policy Act (NEPA) of 1969 as amended ([Pub. L. 91-190, 42 U.S.C. 4321-4347, January 1, 1970, as amended by Pub. L. 94-52, July 3, 1975, Pub. L. 94-83, August 9, 1975, and Pub. L. 97-258, §4(b), Sept. 13, 1982)] 40 CFR Section 1502.14(d)), business and industry, and government agencies and stakeholder groups have undertaken a range of activities in response to historic observations focused on, e.g., land-use and water-use practices that potentially affect the environment. While broadly applied across a range of environmental practices, many organizations explore ways to improve environmental performance, and consequently, life cycle assessment (LCA) has developed as a practice that considers the entire life cycle of a process or product.

For most systems, LCA is a "cradle-to-grave" approach to environmental analysis that addresses, e.g., a manufacturing or construction process, beginning from gathering of raw materials or initiating a construction activity, then moving forward to manufacturing products or developing maintenance and operations for a completed project, and ending with plans for end-of-life management or decommissioning. Each of these aspects of LCA may be assigned to lifetime plots typically captured in the bathtub curve, with LCA potentially serving as a parallel evaluation of all stages of a product's or process's life, particularly their interdependencies given one operation leads to the next. Consequently, LCA enables the estimation of the cumulative environmental impacts resulting from all stages in an activity's or product's "life history." Such an analysis of life history means LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product selection (see, e.g., ISO 1998a,b, ISO 1997).

LCA is an analytical method that assesses environmental aspects and potential impacts associated with a product, process, or service, by:

- compiling an inventory of relevant energy and material inputs and environmental responses;
- evaluating the potential environmental impacts associated with identified inputs and responses;
- interpreting the results to help risk managers make more informed decisions.

As is HACCP, the LCA process is a systematic and phased analytical approach applicable to risk management. LCA may also contribute to a decision-making process, e.g., selecting between two alternatives through comparisons of lifetime costs captured by the process under consideration. LCA may help decision-makers select the products (e.g., pumps and valves) or process that results in the least impact to the environment (e.g., selection of pipeline route), which may link to other factors such as cost and performance data that relates to making a decision. Through LCA, tracking environmental impacts associated with alternative actions can help decision makers and managers fully characterize environmental trade-offs associated with, e.g., land- and water-use. For example, once engineering designs for an alternative of choice, or a winnowed set of alternatives has been identified for serving the water demands of populations of the Red River Valley, performing an LCA as an extension of this preliminary failure and consequence analysis may be indicated and justify the resources and time invested in the activity. Although this preliminary failure analysis does not implement an LCA, the framework supporting that analysis summarized in Section 3 relied on HACCP and LCA guidance (see, e.g., ASTM 2006d, FAO/WHO 1998, WHO 1997), which may serve subsequent engineering design and cost analysis once alternatives of choice are identified.

2.5 Habitat Equivalency Analysis and Assessing Consequences of Control System Failure Analysis

For the evaluation of economic consequences potentially associated with diversion of Missouri River waters via GDU Import to Sheyenne River Alternative and Missouri River Import to Red River Valley alternative, habitat equivalency analysis (HEA) was completed, following methods as previously applied to Red River, Lake Winnipeg, and Red Lake River (USGS 2005a,b). As proposed in the DEIS (Reclamation 2005a), these Action Alternatives involved aquatic resources that motivated the completion of HEA, in order to develop an analysis complementary to that completed for Lake Winnipeg and Red River (USGS 2005a) and Red Lakes and Red Lake River (USGS 2005b).

HEA was selected for this consequence analysis, making it consistent to those analyses in USGS (2005a,b). HEA is a relatively transparent economic approach, and describes consequences in terms of the amount of restoration that would be needed to address potential impacts. The analytic inputs and results of HEA are directly associated with the potentially affected resources and their services, and results of HEA are relatively easily understood by a broad range of interested parties.

2.5.1 Habitat Equivalency Analysis: Model Development. In this section, the HEA model is developed for the consequence analysis. This model is essentially the same used in natural resource damage assessments with one significant difference. Damage assessments are conducted after the occurrence of an ecological injury. Therefore, that analysis is of a certain event. Ecological risk assessments, on the other hand, address uncertain events in the future. To accommodate this uncertainty, the probability of successful biological invasion is introduced into the HEA model development. This probability is applied to the future ecological losses that would occur given a successful invasion. This analysis presents the consequences of this risk as the certain level of restoration that would be required to address these uncertain losses. That is, a certain level of restoration is calculated to offset an uncertain risk of successful biological invasion. This quantification of risk consequences is termed offsetting restoration.

The fundamental criterion behind this application of HEA is characterized by the following relationship:[1]

$$aV^L \sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)} = V^R \sum_{s=s_0}^{s_1} R_s (1+i)^{(P-s)} \qquad [1]$$

where

a	=	Probability of successful biological invasion
L_t	=	Lost services in time period, t
V^L	=	Net economic value per unit of lost services (assumed to be invariant with respect to the scale of loss and time over a relevant range)
R_s	=	Replacement services in time period, s
V^R	=	Net economic value per unit of replacement services (assumed to be invariant with respect to the scale of restoration and time over a relevant range)
t_0	=	Time period when lost services first occur
t_1	=	Time period when lost services last occur
s_0	=	Time period when replacement services are first provided

[1] This relationship is consistent with the expected value criterion for decision making under risk (Thusesen and Fabrycky 2001).

s_1 = Time period when replacement services are last provided

P = Present time period (when the analysis is conducted)

i = Periodic discount rate

The expression on the left-hand side of equation [1] is the expected present value of lost services and the expression on the right-hand side is the present value of replacement services provided by restoration. This criterion requires that sufficient replacement services, R_s, be provided through time to generate a present value that is equal to the expected present value of lost services.

HEA is a specific application of this criterion. The simplifying assumption that is required for HEA is that the replacement services provided by restoration are comparable to the lost services. Specifically, HEA assumes that V^R equals V^L, which simplifies equation [1] as follows.

$$a\sum_{t=t_0}^{t_1} L_t(1+i)^{(P-t)} = \sum_{s=s_0}^{s_1} R_s(1+i)^{(P-s)} \qquad [2]$$

Thus, the value terms cancel out, avoiding explicit economic valuation while continuing to satisfy the fundamental criterion.

If a constant level of replacement services, R, is provided through time, then equation [2] can be modified to allow for the unique solution of the restoration requirement:

$$a\sum_{t=t_0}^{t_1} L_t(1+i)^{(P-t)} = \sum_{s=s_0}^{s_1} R(1+i)^{(P-s)}$$

$$= R\sum_{s=s_0}^{s_1} (1+i)^{(P-s)}$$

and

$$R = \frac{a\sum_{t=t_0}^{t_1} L_t(1+i)^{(P-t)}}{\sum_{s=s_0}^{s_1} (1+i)^{(P-s)}}$$

Replacement services are often quantified by geographic area (e.g., acres of habitat or miles of river). Given that metric, varying levels of effective service provision can be accommodated by assigning varying proportional weights, Q_s, to a constant land area, R, through time. For example, such weights could reflect the increasing efficacy of restoration as planted vegetation grows or is succeeded by the intended climax community. These weights are sometimes referred to as relative productivity, and may be summarized as:

$$a\sum_{t=t_0}^{t_1} L_t(1+i)^{(P-t)} = \sum_{s=s_0}^{s_1} Q_s R(1+i)^{(P-s)}$$

$$= R\sum_{s=s_0}^{s_1} Q_s(1+i)^{(P-s)}$$

and,

$$R = \frac{a\sum_{t=t_0}^{t_1} L_t(1+i)^{(P-t)}}{\sum_{s=s_0}^{s_1} Q_s(1+i)^{(P-s)}} \quad [3]$$

where

Q_s = Relative productivity (proportional equivalence of the net ecological services provided in time period *s* by restoration relative to the baseline productivity of the injured habitat)

Equation [3] is used to determine the scale of offsetting restoration when both lost services and replacement services occur over finite time horizons. Modifications of that equation include situations where some level of lost services continues into perpetuity and where restoration provides some level of replacement services into perpetuity. These modifications are incorporated below:

$$R = \frac{a\sum_{t=t_0}^{t_1} L_t(1+i)^{(P-t)} + \frac{L_{t_1}(1+i)^{(P-t_1)}}{i}}{\sum_{s=s_0}^{s_1} Q_s(1+i)^{(P-s)} + \frac{Q_{s_1}(1+i)^{(P-s_1)}}{i}} \quad [4]$$

where

t_1	=	Time period when a constant level of lost services is achieved
L_{t_1}	=	Constant level of lost services continuing from time period t_1 into perpetuity
s_1	=	Time period when restoration achieves a constant level of replacement services
Q_{s_1}	=	Constant level of relative productivity continuing from time period s_1 into perpetuity

All other variables are as defined for equation [3] above.

The HEA summarized in Section 5 is then considered in Section 6 within the context of the failure analysis of Section 3 where equation [4] is used to calculate the consequences of the potential risks associated with biological invasions. That is, the adverse effects of a successful biological invasion are assumed to continue into perpetuity, and the offsetting effects of restoration are assumed to continue into perpetuity as well.

HEA quantifies the consequences of failure as the quantity of a certain provision of restoration that is required to offset an uncertain risk of successful biological invasion. The same assumptions will be made regarding the nature of this offsetting restoration as in USGS (2005a,b). Specifically, it is assumed that offsetting restoration begins five years after the onset of successful invasion, and requires 20 years to become fully functional. These assumptions will be made to allow sufficient time for planning, implementation, and mid-course corrections under an implementation plan, particularly as that plan captures concerns related to risk management. Once offsetting restoration becomes fully functional, it is assumed to provide replacement ecological services that are equivalent to those potentially lost from biological invasion. These replacement services are also assumed to continue into perpetuity.

3.0 Failure Analysis of Biota Treatment and Interbasin Water Transmission System

Section 3 presents a focused review of materials and processes characteristic of the conceptual systems identified as Action Alternatives in the DEIS, then develops a preliminary analysis of a control system comprised of a water intake module, a biota treatment module, and a conveyance module which follows a simple life-time model consistent with the bath-tub curve characterized in Section 2. Recall that Section 2 included a tabular summary of general attributes linked to failures in buried pipelines, attributes and mechanisms which are extended in this section to other components in the water treatment and water transmission systems envisioned as Action Alternatives (see Section 2, Table 2-1; see also USGS [2005b]). For example, time-independent attributes associated with mechanical damage or incorrect installation may occur in treatment modules and processes as well as pumps, valves, and gates. Failures associated with time-dependent attributes may similarly be linked to built-system components, e.g., corrosion in valves and gates, or material failures in joints between gates and pipes. Some of these failures would increase risks of biota transfer, e.g., by enabling transfers or increasing susceptibility of receiving system, while others would decrease those risks, e.g., through impaired performance of the delivery system.

To lay a foundation for this preliminary analysis, this section initially focuses on a brief overview of fluid dynamics (Section 3.1), since any system selected to meet the water demands of the Red River Valley must reflect processes primarily governed by the fluid mechanics of water flow through pipes. Failure in pipes and mechanical components within the control system may be root-cause failures in water-transfer systems, which directly or indirectly will reflect hydraulic factors in the system. Such failures potentially mediate releases of biota coincidentally associated with water delivery, e.g., interaction of pressure transients and age-related condition of treatment and conveyance components of the system. This brief overview of fluid mechanics anticipates engineering design and analysis of Action Alternatives that should be developed once a fully specified system has been identified as engineering selection(s) of choice. Once identified, these systems would be amenable to evaluation using hydraulic models for higher resolution analyses of failure risks characterized by component-specific empirical data.

Following this brief overview, general mechanisms linked to infrastructure failure will be summarized (Section 3.2), particularly sources linked to increased or decreased risks associated with:

- Corrosion (Section 3.2.1)
- Fatigue (Section 3.2.2)
- Materials defects (Section 3.2.3)
- Earth movments (through, e.g., frost heave and earthquakes; Section 3.2.4).

This summary is followed by a preliminary analysis of system failures based on a simplified control system consisting of a 3-component series that includes (1) an intake component, (2) a treatment component, and (3) a transmission component (Section 3.3). This preliminary analysis relies upon empirical data and existing information collected and compiled as noted in Section 2, then considers those empirical data to exponential and Weibull models briefly outlined in Section 2 and detailed in Appendix 1. The link between control system failure and biota transfers potentially resulting from such failure is considered through a narrative analysis of risks, which is subsequently placed within the context of landscapes or habitats at-risk in Section 4. Consequences potentially linked to the intersection of control system failure and habitats at-risk are highlighted by the HEA detailed for Sheyenne River-Lake Ashtabula in Section 5, then considered relative to control system failure in Section 6.

Exceptions to preliminary analysis. Given the design parameters currently developed for the Action Alternatives summarized in the DEIS, some factors noted in Table 2-1 will not be considered in the following preliminary analysis. An absence of consideration, however, should not be inferred as their being insignificant sources of risks of failure associated with:

- Third-party actions
- Operator actions

The range of potential breaches to nominal system performance are numerous, and once alternatives of choice have been identified—be those within-basin or interbasin dependent—fully developed engineering designs can incorporate quality assurance programs to minimize failures linked to materials, construction, and installation of control system components, e.g., following best available guidance available (see, e.g., ASCE guidance in place [ASCE 1998] or under development, e.g., http://www.asce.org/instfound/techcomm_pld_location.cfm). Technical and management practices illustrated by these guidance documents reflect an awareness of

- pipeline location practices and procedures including application of survey techniques and assessment of environmental impact;
- pipeline installation methods including both normal and special techniques; and
- quality assurance, proof testing, and inspection practices on constructed pipelines, and to cooperate with other organizations in gathering and disseminating this information to the profession.

In addition to failures linked to out-of-specification materials or construction practices, evaluation of failures potentially linked to malicious actions of third parties may also be incorporated into detailed engineering plans, once those are identified as needs of the larger project envisioned by DWRA. Given the heightened awareness of water-system security, much of the available guidance reflects water utility concerns; however, the water treatment and water-transmission system's detailed design may benefit from relatively recent compilations by, e.g., Murphy et al. 2005, Hogan and DeBoer 2005, M.B. Corporation 2004, and May 2004. Guidance to secure control systems from intentional breaches range from primers on security-related problems common to water transmission and distribution systems to procedures for decision-makers developing policies to address these issues (see, e.g., Michael Baker Corporation 2004). Once detailed engineering designs are available, potential threats and the system's vulnerability to those threats can be considered. For example, plans could be developed for proactive crisis management, emergency preparedness and disaster planning, including emergency response and response team coordination, as well as communications with first responders, news media, and public officials. These security-related planning efforts are merely acknowledged in this preliminary failure analysis, but can be more fully developed as integrated features of engineering designs wherein a HACCP process may help secure water transmission systems by

- identifying points of potential intrusion,
- integrating evaluation of consequences of system failure (e.g., as breach event during unperturbed system performance as in, e.g., "short circuiting" in membrane treatment, or malicious destruction of transmission lines or components),
- recommending enhancements to improve security of existing components, e.g., McClusky Canal or Lake Ashtabula as source water, and

- recommending design considerations for enhanced security of new infrastructure or future additions to initial-build components (e.g., extension of initial-build water transmission lines).

It must also be noted that routine practices, e.g., operational flushing to maintain water freshness or disinfection residual, are not explicitly incorporated into this preliminary analysis. However, these routine elements in operations and maintenance (O&M) procedures would currently be captured by the preliminary analysis, given the primary scenario developed in Section 3 of this report.

3.1 Fluid Dynamics, Leaks, Breaks, and Bursts

Avoiding sudden pipe breaks and bursts in water transmission pipelines such as any of those identified in the DEIS involves a long-term commitment of resources. Service interruptions, the cost of repair and damage to surrounding property, and infrastructure associated with the system operation require dedicated infrastructure management plans. For example, costs associated with the pipeline breaks can be reduced by minimizing the time required for detecting and locating a break. While the preliminary analysis considered in this investigation does not consider hydraulic models better suited for analysis of a fully developed engineering design, the failure analysis initiated by this report considers the control system's hydraulic attributes key to the analysis of failure, particularly as those relate to pipe leaks, breaks, and bursts. In the current investigation, distinctions among these conveyance-related sources of water loss are considered relative to the system's capacity to "make up" for loss of head pressure.

Leaks in piped water occur largely as undetected contributions to water loss, primarily because these losses occur within the operational norms of the system. That is, the variance in hydraulic characteristics of the water transmission system does not routinely allow detection of leaks in conveying water from source to receiving area. Leak tests may be incorporated into maintenance and operations schedules, but unless specific tests are implemented, the force behind moving water within the system is sufficient to maintain water flows at given pressures despite the leaks. Leaks may occur beyond a simple measurement related to operating pressures and maintenance of nominal flows. For our purposes, the distinction between leaks and breaks may be characterized as being one where compensatory responses must be made to compensate for water loss taps to system head. In contrast, pipe bursts are simply breaks wherein system compensation is not possible or not practical, and system integrity is jeopardized sufficiently to warrant partial or complete shutdown.

Although the preliminary failure analysis summarized in this section considers system performance as an oversimplified binary state—control system of water treatment and water transmission works per specification and is online, or control system of water treatment and water transmission does not work per specification and is offline—an engineering analysis fully developed on alternative(s) of choice would likely increase the resolution of potential failures occurring in the system. For example, pressure transient monitoring may be more fully developed in a hydraulic analysis once the specifications for the water transmission system are resolved, and would provide support for developing monitoring programs for detecting and locating breaks in pipelines. Various hydraulic models have been proposed to detect leaks in water distribution systems (see, e.g., Pudar and Ligget 1992, Ligget and Chen 1994, Liou and Tian 1995, Liou 1998, Andersen and Powell 2000), yet few have been field tested or validated (Misiunas et al. 2005). Similarly, methods to evaluate "leak-before-break" behaviors may also be available that would sufficiently characterize the system of choice, and empirical data, e.g., hydrostatic burst tests, may be available for line pipes once selected for construction (i.e., pipes of ductile iron versus steel versus polyvinyl chloride). Thus, the control system's engineering design could be responsive to stakeholder concerns.

3.1.1 Fluid dynamics of flow in pressure pipes: laminar and turbulent flow. In laminar flow, fluids move along parallel paths or streamlines. In contrast, turbulent flow occurs when fluid layers are mixed and follow irregular paths, e.g., eddies. The point where flow transforms from laminar to turbulent is identified by a critical point, which is generally characterized by a system's Reynolds number. The Reynolds number is dimensionless and key to fluid dynamics, as it reflects the ratio of inertial forces to viscous forces associated with the fluid. Reynolds number (R) is defined as

$$R = \frac{\rho VD}{\mu} = \frac{VD}{\upsilon}$$

where

V = mean fluid velocity,
D = characteristic dimension (equals pipe diameter, if a cross-section is circular),
ρ = fluid density,
μ = (absolute) dynamic fluid viscosity, and

ν = kinematic fluid viscosity, or ν = μ/ρ.

The transition between laminar and turbulent flow depends on flow configuration and must be determined experimentally, often referred to as a critical Reynolds number. With circular pipes the critical Reynolds number is generally accepted at values around 2300. Engineers tend to avoid pipe configurations that fall within the range of Reynolds numbers from about 2000 to 4000 to ensure that the flow is either laminar or turbulent (that is, laminar flow predominates system when R < 2000). Optimal designs are intended to avoid turbulent flow, since it results in more frictional head loss than with laminar flow.

Hydraulic Radius. The hydraulic radius is the flow area (A) divided by the wetted perimeter (P)

$$R_h = \frac{A}{P}$$

and for a circular pipe flowing full

$$R_h = \frac{\pi r^2}{2\pi r} = \frac{r}{2} = \frac{D}{4}$$

Friction Head Losses. The Bernoulli or Energy Equation for a incompressible fluid can be characterized as

$$\left(\frac{p_1}{\gamma} + z_1 + \frac{V_1^2}{2g}\right) + h_M - h_L = \left(\frac{p_2}{\gamma} + z_2 + \frac{V_2^2}{2g}\right)$$

where the pressures, velocities, and elevations of the system are valued as *p*, *V*, and *z*, respectively, with the pump energy (h_M) derived from the pump equation for the system (see Reclamation 2005c; see also Rishel 2002, Tuzson 2000, Karassik et al. 2001, Sanks et al. 2006). The remaining term—head loss for the system—stems from frictional losses, which for circular pipes of constant cross-section can be determined using the Darcy-Weisbach Equation

$$h_L = f\frac{L}{D}\frac{V^2}{2g}$$

where

L = pipe length,
D = pipe diameter,
V = velocity of fluid in the pipe
f = friction factor, and
g = force of gravity.

Head loss is largely due to viscous effects that create shear stresses in the flow, with the maximum shear stress (τ_0) occurring at the pipe wall surface.

$$\tau_0 = \frac{f}{4}\rho\frac{V^2}{2} = \frac{f}{4}\gamma\frac{V^2}{2g}$$

For laminar flow in circular pipes, the friction factor (*f*) is

$$f = \frac{64\nu}{DV} = \frac{64}{R}$$

where

R = Reynolds number.

Laminar flow develops through viscous forces in the fluid. Flow near the beginning of a pipe does not develop full laminar flow until the entrance length (L_e) is passed, which is a function of the Reynolds number and the pipe diameter

$$L_e = 0.058RD.$$

Turbulent flow develops over the length of a pipe similar to laminar flow. Turbulent flow has a laminar, viscous boundary layer near the pipe's inside surface which is a function of Reynolds number and surface roughness. Velocity profiles for turbulent flow depend on values for smooth and rough pipe surfaces, e.g., friction factors for turbulent flow may be determined graphically from a Moody diagram, which graphically represents values of Reynolds number and relative roughness (Moody 1944). Relative roughness is characterized as (e/D), where e is the absolute roughness or effective pipe roughness height and D is pipe diameter.

Empirical Equations For Single Pipe Flows. For water flows where V < 10 fps, the Hazen and Williams Equation typically applies to pressure pipe flows, while water flows in open conveyances under atmospheric pressures (e.g., Sheyenne River) follow the Manning Equation.[1]

Generalized Head Loss and Minor Losses in Turbulent Flow. Head loss due to friction (h_f) can be estimated by the Darcy-Weisbach equation. Transitions in pipe systems, e.g., bends, valves, changes in diameter, entrances and exits, cause head losses in the system referred to as minor losses, which are dependent on component-specific loss coefficients (Table 3-1).

Table 3-1. Examples of minor loss coefficients

Transition	*k*
Entrance, bell-mouthed	0.04
Entrance, square edged	0.5
Entrance, reentrant	0.8
Discharge	1.0
Globe valve, wide open	10.0
Angle valve, wide open	5.0
Gate valve, wide open	0.19
90-degree radius elbow	1.50
45-degree elbow	0.42
T, through side outlet	1.8

A minor loss is usually a function of the velocity head as follows:

$$h_{L(Minor)} = k\frac{V^2}{2g}$$

[1]For water flow in open channels, hydrological analyses typically apply, e.g., the Manning Equation

$$V(fps) = \frac{1.486}{n} R_h^{2/3} S^{1/2} \quad (BG)$$

$$V(m/s) = \frac{1}{n} R_h^{2/3} S^{1/2} \quad (SI)$$

where

n = Manning roughness coefficient (0.010-0.040) and for relatively sudden decreases in pipe diameter, values for *k* vary widely, depending on the extent of diameter change, the length over which that change occurs, and the design feature demanding the change in pipe diameter. For relatively sudden expansions in pipe diameter $h_{L(Minor)}$:

$$h_X = \frac{(V_1 - V_2)^2}{2g}$$

and for gradual increases in pipe dimeter $h_{L(Minor)}$ may be estimated

$$h_X = k' \frac{(V_1 - V_2)^2}{2g}$$

Bends and elbows in pipe systems also confer head losses to the system, which may also be characterized to with system-specific values for *k*. Action Alternatives range from simple linear pipe arrays to those having water distribution-like configurations, and each will display different hydraulic characteristics that influence likelihood of failure.

Single Pipe Flows with Minor Losses. When minor losses are included, the total head loss in the pipe system becomes

$$h_{L\,(Total)} = h_{L\,(Pipe)} + \sum h_{L\,(Minor)}$$

which, when considered within the context of the Bernoulli equation leads to estimates of head loss across the system. Head loss reflecting minor losses linked to a pump or turbine in the pipe reach may be similarly estimated.

Flow in branching pipes. Flow in branching pipe systems are simply solved as the sum of flows:

$$Q_1 = Q_2 + Q_3 + Q_4 + Q_{5\ldots} + Q_n.$$

when the elevation of P is common to all pipes.

Flow and head loss in pipes in series and parallel. Flow and head loss in pipes in series can be solved as

$$Q = Q_1 = Q_2 = Q_3$$

$$h_L = h_{L1} + h_{L2} + h_{L3},$$

and in parallel pipes as

$$Q = Q_1 + Q_2 + Q_3$$

$$h_L = h_{L1} = h_{L2} = h_{L3}$$

Pipe Networks. Branching pipe systems, such as that conceptually considered in the GDU Replacement Pipeline Supply Alternative, can be estimated assuming the flow into any junction is equal to the flow out of that junction, any single pipe conforms to the pipe friction laws within that pipe system, and the sum of the head losses around any closed loop must equal zero. As the engineering designs for the control system gain greater resolution, the iterative process of refining failure estimates based on heightened hydraulic specifications can narrow error estimates about time-to-failure. These refined outputs from a hydraulic-based analysis may also identify areas within a water transmission system, e.g., marked changes in pipe diameters, operating valves and booster pump stations whose nominal operation potentially alter fluid flow, that might initiate events related to transient pressure changes that may yield age-dependent responses in a system at-risk.

Pressure transient strategies. In water pipelines, pressure transients are caused by rapid flow rate changes, and are commonly referred to as surge or water hammer. As indicated previously, changes in pressure occur whenever there is a change in the velocity of flow. Pressure transients are not uncommon events in water pipeline systems and may contribute to operational problems. In worse-case scenarios, pressure transients cause system failure. Engineering designs of water transmission system account for pressure transients, however, and are key to managing risks associated with, e.g., biota transfers linked to long-term performance of the system. Pressure transient control strategies are system specific, based on its minimum and maximum pressure goals. Once alternatives of choice are identified, engineering constraints on pressure transients should result as an outgrowth of the system's design.

Typical causes of pressure transients include the opening and closing of control valves, the starting and stopping of pumps, sudden electrical power failures, and increased or decreased rates of delivery of water from sources to points of destination. Transients may be undetected, if system monitoring is not sufficient, which may lead to an event or a series of events linked to transients that exceed the design pressure of a pipe. Left unchecked, these out-of-design events may affect a transmission system's delivery efficiency, weaken a pipeline, and make it vulnerable to leakage or rupture as breaks or bursts.

To manage pressure transients and system performance in general, O&M commonly focuses on, e.g., faulty or insufficiently placed air valves, faulty valve actuators, isolated surge chambers, faulty or inadequate pumps, and pipeline management procedures. Various types of anomalous transients may occur immediately following construction, while others develop over time. As with many risks, some potentially adverse events can be controlled, while others may be stochastic or exist outside the pipeline system's range of control, e.g., electrical power failures, and may occur without warning. As such, pressure transients will occur in water pipeline systems and may cause or contribute to operational problems or system failure. Transient analyses must be considered during system design to understand the potential magnitude of pressure transients and, if necessary, to determine how they should be adequately controlled. Depending on the system design, numerous equipment and operational alternatives are available for hydraulic engineers to develop a transient control strategy, which will typically be a function of the characteristics and transient constraints of the system.

3.1.2 Water transmission and distribution systems. Water transmission and distribution systems include pumps, valves, joints and connections, storage tanks and reservoirs, and other components as dictated by water demands and receiving system needs. Transmission and distribution systems may be simply characterized as linear pipelines, grids, branching systems, or a combination of these pipe layouts. Transmission systems such as those captured in conceptual designs characterized in the DEIS (Reclamation 2005) are generally dominated by linear series of pipes, although Action Alternatives such as GDU Replacement Water Supply Pipeline Alternative resemble a water distribution grid or combination system as noted in USGS (2005b). For water distribution systems, grid systems are generally preferred to a branching systems, because grid systems can supply water to any point from at least two directions. Grid systems also assure greater likelihood of uninterrupted service, since pipe ruptures that have disabled a part of the system may be isolated for repair without disrupting service to large areas.

Transmission pipelines tend to be simpler in geometry as illustrated by the GDU Import to Sheyenne River Action Alternative (see Section 1). As indicated in Reclamation (2005c), pipelines envisioned as part of any Action Alternative must be installed with proper bedding and backfill. Soil compaction under the pipe (bedding) as well as above the pipe (backfill) is necessary to provide proper support. Pipes must be able to resist internal and external forces as well as corrosion. Water pressure inside the pipes, the weight of the overlying soil, and vehicles passing over them place stress on pipelines. In addition, metal pipes may subject o corrosion internally, if the water supply is corrosive, or externally, because of corrosive soil conditions. Pipelines may also have to withstand water hammer, which occurs, e.g., when valves close too rapidly, yielding pressure surges through the system. Maintaining pipelines is critical to operating the system to meet performance criteria.

Transmission system pumps. Depending on a water transmission system's configuration, a variety of pumps may become part of the systems, ranging from intake pumps to booster pump stations located within the pipeline. As engineering designs mature, specific applications will clearly indicate the kinds of pumps required within the system. For example, withdrawal of Missouri River waters via radial collector well networks would require well pumps lift water from the river's alluvial aquifer, then move those source waters to the nearby biota treatment facility. In contrast, water withdrawal from the McClusky Canal has presently targeted use of wet-sump pumps, which would serve as low-lift pumps to move surface water from the canal to the nearby biota treatment plant. Low-lift pumps are generally characterized by their moving large volumes of water at relatively low discharge pressures, while pumps that move water, e.g., from the biota treatment plant to the transmission pipeline would be high-lift pumps operating at higher pressures. Booster pump stations would be located as required to maintain peak flows in the pipeline system, and as such, would serve to maintain pressure within the transmission system.

Horizontal centrifugal pumps and vertical turbine pumps are commonly used in water transmission and distribution systems. Through rapidly rotating impellers, these pumps add energy to the water and move water through the system. Flow rates through these pumps are inversely related to the pressures maintained within the pump casing (i.e., the higher the pressure, the lower the flow or discharge). Vertical turbine pumps often have multiple stages or bowls. The number of stages is dependent on the amount of discharge head required. As conceptual system designs identified by Reclamation (2005c) gain resolution, specific pump types and their roles within the system will lend themselves to engineering failure analyses developed subsequent to this preliminary analysis.

Transmission system valves. The application and location of valves are but one system fitting that presently is undeveloped in conceptual designs, yet any water transmission and distribution system will require several valves to maximize system performance. A wide range of valves may be incorporated into system designs, but regardless of specific applications, valves simply control the quantity and direction of water flow. For example, gate and butterfly valves will generally occur throughout the system to control the rate of water flow and isolate segments throughout the system. Similarly, in water transmission lines, pressure relief valves control static pressure reducing the risk of pipe failure due to high pressures and permit the use of lower pressure class pipe. In a pressure-pipe system, air relief valves will be incorporated into engineering designs at high points in pressure lines, while blow-off valves will be positioned at low elevations and dead-ends within the system to allow for relieving the system as needed.

In water transmission and distribution systems, valves control the flow water, e.g., valves serve to isolate pipe reaches for maintenance and repair. Control valves—pressure reducing valves, altitude valves, and pump control valves—are designed to control pressures and regulate water flow, while air relief valves vent trapped air from the system. Check valves allow water to flow only in one direction (Tullis 1989, Skousen 2004).

Butterfly and gate valves are common in water transmission and distribution systems, most frequently used for isolating equipment and piping. Depending on the system's design, butterfly valves may be preferred, since these tend to be easier to open than gate valves. However, from a fluid dynamics perspective butterfly valves generally have greater friction loss when open (Skousen 2004).

Within a water transmission system, check valves are intended to restrict water flow in one direction, e.g., anti-siphon valves. Air release valves allow air trapped in the line to escape and are critical to maintain the cross sectional area of the pipeline so as not to restrict flow and eliminate pressure transients. Air release valves are also used on booster pumps and wells to removed trapped air, as well as along transmission routes where elevation changes may lead to "air pockets" in route. Combination air release valves allow air to enter a system of pipes, if a vacuum occurs, and are used to vent lines when being drained or in case of pipe failure, preventing the pipe from collapsing.

Control valves are designed to control the flow of water by responding to changes in the system that lead to their automatically opening or closing the valve to compensate, e.g., for pressure changes or changes in flow. These valves are hydraulically-operated, diaphragm-actuated globe valves, with a control mechanism incorporated into the valve's design to assure its specific application, e.g., a pressure-reducing or pressure-relief valve, a pump control valve, or a check valve. An altitude valve is a control valve designed to control levels in storage reservoirs within a transmission system. Pressure-reducing valves occur within a transmission system where elevation differences may be linked with out-of-specification system pressures, and serve to reduce and maintain steady pressures downstream of the valve (Skousen 2004). Control valves are incorporated into the Supervisory Control and Data Acquisition System (SCADA) to allow system operation around the clock. Additionally, stainless steel bolts are specified to extend the life of the valves and fittings, and reduce the possibility of failure.

Storage tanks and reservoirs. Within a water transmission system, storage tanks and reservoirs help maintain operating pressures. Enclosed or covered storage tanks have been included in Action Alternatives in conceptual designs identified in the DEIS (Reclamation 2005a). Depending on the environmental setting, water storage tanks may be built at ground level or on higher elevations in areas with relatively flat topography. Alternatively, ground-level storage tanks with booster pumps may be used.

Reservoirs are classified as underground, ground level, elevated, or standpipe. An underground reservoir or basin may be at or below grade level and formed either by excavation or embankment. Systems must incorporate covered reservoirs into their design in accordance with SDWA, minimizing contamination with dust-borne microorganisms and other contaminants, while helping control algal growth. Surface reservoirs may be lined with concrete or membranes.

Pipes. Several different types of pipe may be used in water transmission and distribution systems, with each having its advantages and disadvantages related to cost, installation, strength, and corrosion. Pipes commonly used in MR&I systems are ductile iron pipe (DIP), steel pipe (ST) or welded steel pipe (WST), polyvinyl chloride (PVC) pipe, and High Density Polyethylene (HDPE) pipe. DIP and WST are usually cement-mortar lined. While the range of pipe materials reflects the strengths and weaknesses of each material under given engineering designs, the current investigation has focused on DIP, ST or WST, and PVC as pipe material of choice (see Section 3.2.3).

All of these components must be incorporated into a water transmission system's design, and as a network, the primary mission of pumps, valves, storage tanks, and pipes is to move water from one location to another.

Transmission system hydraulics. As indicated by the brief overview of fluid flow, a number of factors govern the dynamics of moving water through a water transmission system. As water moves through the system, hydraulic factors affect pressures, flow, and forces exerted against the pipes within the system. As water flows through a pipe a certain amount of energy must be expended to overcome the friction between the water and pipe's wetted surface; hence, friction loss occurs. Friction loss in water lines varies with pipeline length, pipe diameter, pipe material, and with pipe age, and is usually offset by increasing the pumping pressure in order to maintain a given flow through the pipe. As pipes age, their inner surfaces get rougher and friction increases, although routine O&M schedules may reduce roughness, e.g., through pigging the DIP or ST lines to remove scale or tuberculation linked to chemical interactions between pipe materials and water being conveyed within the system. Friction loss, however, is not the only component of water loss, and in aging systems, may represent a relatively small contribution to total. In a water transmission system, leaks and malfunction in system components also occur, and might become problematic if unattended.

Pressure transients commonly occur when water is moving through a transmission pipeline then relatively sudden changes in flow rate occur, creating a pressure surge commonly referred to as water hammer. The greater the change in flow, the greater the water hammer. Severe water hammer can rupture transmission lines. Once created, pressure surge travels down the line, potentially exerting systemic effects. Operation of valves within the system is critical to control pressure transients, and pump control valves serve to protect system pumps and reduce water hammer. The system's configuration will also influence the role of pressure transients. Bends and fittings throughout the system piping should be resisted by thrust blocks or the adjacent pipe joints be restrained to support and protect the system in these vulnerable locations. Bend, elbows, and tees within a water transmission and distribution system are frequently critical areas in determining the negative effects of pressure transients on system performance. Fluid flow through these, e.g., curvilinear features of a pipeline are linked to subtle to marked pressure changes, which in part reflect how flexible these pipe joints are. Hydraulic forces tend to open the joints nearest, e.g., bends and other pipe fittings, and the magnitude of this force varies with the amount of bend, the diameter of pipe, and the locally-occurring internal pressures. Engineering designs compensate for these hydraulic forces through installation of restrained joints sufficient to resist the thrust in these areas.

3.1.3 System failure. Pipelines serve to move many commodities, ranging from highly hazardous gases and petroleum products to irrigation and water intended for municipal and industrial use. Across many years of service and across this range of commodities, pipelines have established performance and safety records, but inevitably, failures have occurred and have been linked to a number of causes. These events range from being relatively benign, to inconvenient, to catastrophic, and despite a range of regulations that have lead to standards and codes guiding the installation and operation of pipelines, failures persist. For example, pipeline wall thicknesses are specified, based on allowable pressure in the line and on the allowable hoop stress for the pipe material (Gagliardi and Liberatore 2000, AWWA 1999a, Mays 1999, 2000). Also, as part of the construction and inspection process, pipelines are pressure tested and materials are subject to nondestructive tests to assure within-specification condition prior being in-service. Pipelines are usually hydrostatically stressed to levels above their working pressure and near their specified minimum yield strength (see, e.g., Larock et al. 2000, Mielke 2004, Mohitpour et al. 2005, Muhlbauer 2004, Reed et al. 2004, Tullis 1989).

Despite standards and codes supporting construction and operation of pipelines, pipeline failures of various magnitudes occur, frequently linked to mediating factors such as (see Section 2, Table 2-1)

- External or internal corrosion
- Fatigue cracks
- Material defects
- Weld cracks
- Improper repair welds
- Incomplete fusion
- Hydrogen blistering
- Mechanical damage

Water leakage and pipe breaks. One of the most common problems is water loss, especially from a distribution system. In most water distribution systems, some percentage of the water is lost in transit from treatment plants to consumers; water loss typically ranges between 5% and 20% of production (AWWA 2003a, Grigg 2005, Kirmeyer et al. 1994, Kleiner et al. 2005, Mays 2000). Although transmission systems may be simpler in design, e.g., fewer customer service taps and fewer taps to pipeline, leakage is usually present in any water transmission system. There are many possible causes of leaks including:

- pipe material deterioration
- partial or total failure of pipe joints
- earth movements (e.g., frost heaving or earthquake)

and frequently, a combination of factors leads to occurrence of leaks. Leakage occurs in various components of a system, including transmission pipes, fittings and connections within the pipe system, pipe joints, and valves. The material, composition, age, and methods joining system components influence occurrence of leaks, which may lead to breaks and bursts. Causes of leaks include corrosion, cracks, material defects or failure due to deterioration over time, faulty installation, inadequate corrosion protection, ground movement over time due to drought or freezing, and repeated excessive loads and vibration from road traffic. For example, old pipes within a system may leak water through corroded areas, cracks, and loose joints which may develop into pipe bursts, resulting in sudden loss of water pressure and flooding. Although performance criteria will vary with engineering experience and on system function (e.g., transmission function versus distribution function), a "reasonable goal" for pipe break rate in water distribution systems in North America has been estimated at 25 to 30 breaks per 100 miles of pipe per year (15 to 19 breaks per 100 km; see AwwaRF 1995). Given differences between water transmission and water distribution networks, these goals are primarily noted to provide interpretative context for this preliminary analysis.

Common causes of pipe breaks. Cold temperatures frequently lead to increased depths of freezing in the soil column, which is often linked to breaks in water pipes. In areas prone to increased freezing depths and other aggressive soil conditions, secondary protection may be installed inside metallic pipes, e.g., such as pipe coatings or plastic sleeve liners. A simple list of causes linked to pipe corrosion include:

- metal pipe material
- interactions between pipe and soils
- soil properties and contamination
- difference in soil moisture regimes surrounding pipe
- soil pH
- microbial interactions (internal and external to the pipe)
- pipe-to-pipe dissimilarities, e.g., unions between pipes of fabricated from different materials
- differential aging of pipe, including routine O&M replacement schedules that effectively mix new pipe with old pipe
- pipe surface imperfections (e.g., associated with pipe manufacture or installation)

- interactions related to hydraulic-system age (including stress corrosion)
- stray currents

Pipe corrosion is a common root-cause or contributing factor to pipe failure, and is briefly considered in Section 3.2 which focuses on failure mechanisms most likely to affect transmission system performance.

3.2 General overview of failure mechanisms

For this preliminary analysis of failures that might play a role in biota releases collateral to an interbasin water diversion, each section that follows briefly summarizes corrosion, fatigue, materials, and earth movement processes considered most likely linked to failure events.

3.2.1 Corrosion. In the US, direct costs of corrosion exceed $270 billion per year (NACE, 2001). Much of this corrosion involves infrastructure made of steel and iron. Hence, pipes and other infrastructural components of proposed water transmission facilities outlined in DEIS (Reclamation 2005a) will deteriorate over time, and a range of failure modes in water withdrawal, treatment infrastructure, and transmission pipelines will potentially be derived—directly or indirectly—from corrosion. As part of the preliminary failure analysis, the following summary is focused on corrosion, its origins and development through time, and the tools available to reduce and control corrosion damage in water transmission systems included as Action Alternatives. Corrosion effects have long been included in reliability analysis of structural steel and iron, as well as for a range of pipe materials—steel, iron (both ductile iron and cast iron), and concrete pipe—and components of water transmission and distribution systems (see, e.g., Abernathy and Camper 1997, Ahammed 1998, Ahammed and Melchers 1996, 1994, ASTM 2006a,e, AWWA 2004, AwwaRF/DVGW-TZW 1996, De Leon and Macías 2005, Duranceau et al. 2004, Peabody 2001, Roberge 2000, Schock 1999).

As a result of environmental exposure, corrosion generally appears at several locations in a system, e.g., in a series of interconnected pipes segments, rather than at a single location. Hence, a system not only changes through time, but is often spatially vulnerable, which is frequently expressed as common root-causes of corrosion (either internal or external) over pipeline segments. Spatial correlation exists between targets of corrosion and the corrosion process which occurs throughout the lifetime of any water system and consequently reduces system reliability. Corrosion also plays a role in the aging of other control system components such as valves, gates, and pumps, which leads to a heightened awareness of corrosion's role in mediating system failures potentially associated with biota releases. Thus, deterioration linked to corrosion diminishes pipeline safety and reliability through time. In part, the characterization of risks related to aging processes such as corrosion that might mediate or serve as a contributing factor to system failure may identify technical practices incorporated into future risk management plans for system operation, e.g., development of schedules for inspection and maintenance of pipelines and control system infrastructure.

Corrosion basics. Corrosion can be uniform or of a pitting nature where penetration rates can be very high. For corrosion to occur, there must be: (1) an anode, (2) a cathode, (3) a conducting metal between anode and cathode, and (4) a conductive fluid, with metal dissolution occurring on the anion side of the chemical reaction. Corrosion rate is typically expressed in *mpy* (mils or thousandths of an inch per year). CO_2, H_2S, O_2, other aggressive anions, and microbes can all contribute to corrosion. Metallurgical properties and stress points within a metal resulting from its manufacture generally influence where corrosion starts. Other age-related processes also serve to reduce a materials performance, e.g., steels and irons are also susceptible to hydrogen damage (hydrogen cracking of high strength steels under tension, stepwise or blister cracking on non-stressed, medium strength steels), corrosion fatigue, and alternating tensile stress.

The severity of corrosion in susceptible materials is influenced by: (1) pH, (2) temperature, (3) pressure, (4) velocity, (5) wear and abrasion (wear-accelerated corrosion), (6) oxygen concentration, and (7) galvanic and (8) microbial activity. Corrosion increases at pH less than 7, and temperature will only become a major factor in the corrosion process, if operations occur at less than 110˚F. Pressure affects solubility of corrosive gases, e.g., CO2, which in turn increases corrosivity. The velocity of materials moving through pipes may also have a major effect on corrosion, depending on the chemical makeup of the transferred material, e.g., for corrosive water in steel pipe, the limiting velocity is in the 6-12 fps (ft/sec range). Galvanic corrosion is self-generating and results when dissimilar metals are components of the system; differences in the electronegativities of these materials will determine the role that galvanic corrosion plays in the system. Galvanic corrosion also occurs in soils that have low soil resistivity (<1,000 ohms/cm in the presence of water). Microbial activity can aggravate corrosion within the system, and may occur under aerobic, anaerobic, acid-producing, or sulfate-reducing conditions. For example, aerobic microbes occurring in biofilm communities can reproduce with as little as 0.5 ppm oxygen and may contribute to the corrosion process.

Uniform corrosion. Uniform corrosion tends to be a surface phenomenon that occurs at a steady, often predictable rate. This predictability facilitates control, however, and the common approach to offset corrosion losses linked to uniform processes is to make the material thick enough to function for the lifetime of the component. Uniform corrosion can be slowed or stopped by reducing the movement of electrons between the environment and the target material through surface coatings (e.g., with a non-conducting medium such as paint, oil, or polyethylene wraps) or through reducing the conductivity of the solution in contact with the metal (e.g., keep the contact surface dry, or alternatively, regularly wash conductive reactants from the target material's immediate environment). From an engineering perspective, slowing down or stopping oxygen from reaching the material's surface, e.g., through application of protective coatings, is a preferred solution, although alternative methods have been developed such as preventing a metal from yielding electrons by using a more corrosion resistant metal higher in the electrochemical series as a treatment, e.g., use a sacrificial coating which gives up its electrons more easily than the metal being protected. Depending on engineering needs, cathodic protection or chemical inhibitors also may be employed to reduce corrosion potential.

Pitting corrosion. Pitting corrosion occurs in materials that have an imperfect protective coating or film such as an anti-corrosion coating that breaks down. The exposed metal subsequently yields electrons and the corrosion process begins, usually originating as tiny pits where localized corrosion reactions are initiated. Control can be ensured by selecting resistant materials for exposed structural members, or in piping, by ensuring sufficient flow velocity to minimize contact times between inner pipe surfaces and contained fluids, thus reducing initiation of the corrosion process. If the engineering application allows, washings and use of inhibitors may also benefit the corrosion-control process, as would the application of protective coatings. Regardless of countermeasures, corrosive pits may serve as crack initiators in stressed components or in those components bearing residual stresses linked to their manufacture. Once initiated, pit corrosion processes may lead to stress corrosion cracking (SCC).

Localized corrosion. The consequences of localized or "diffusive pitting corrosion" tend to be more severe than uniform corrosion, because failures follow a generally less predictable and quicker onset process.

Galvanic corrosion. When two different metals contact each other, differences in their electronegativities are associated with a plating process wherein one material yields electrons to the other. Engineering designs can minimize the occurrence of galvanic corrosion, yet other electrochemical and electromagnetic processes remain problematic, especially within the context of the aging system. Galvanic corrosion occurs when three basic conditions exist: the materials are in electrical contact, one metal is significantly better at giving up electrons than the other, and pathways are available for ion and electron movement between the dissimilar materials. These conditions, however, may be considered in developing countermeasures that simply reduce or eliminate their occurrence; namely, using insulators or coatings to interrupt the electrical contact between the metals, select metals close together in the galvanic series, or prevent ion movements between materials (e.g., by coating the junction with an impermeable material or by ensuring a dry environment between surfaces or conducting materials are not present).

Selective attack. This type of corrosion occurs when one component or phase is more susceptible to attack than another and corrodes preferentially, leaving a porous matrix lacking structural integrity. Although most frequently observed in alloys or in older cast irons, selective corrosive attacks may occur in any metal matrix comprised of components characterized by differing electrochemical properties. Selective attacks effectively result from differential corrosion rates among constituents of, e.g., a pipe matrix. As such, selective attack may be avoided by selection of a resistant composite material or through other means, including the use of protective coating, reducing the aggressiveness of the environment (e.g., selection of appropriate bed and backfill materials), and using cathodic protection.

Electrolysis and stray current corrosion. When direct current (DC) enters metal pipe, it runs the course of the pipe, then discharges to ground in the process of electrolysis. This form of corrosion yields plating of the source metal into the surrounding soil. Any DC machinery or telemetry equipment that is grounded to water transmission lines will cause electrolysis.[2] When a direct current flows through an unintended path, the flow of electrons initiates and supports corrosion. Stray current corrosion commonly occurs in soils, in flowing, or in stationary fluids. The use of plastic pipe will eliminate electrolysis, since plastics such as PVC are non-conductors. Effective remedies frequently applied to controlling the electrolysis and stray current corrosion include insulating the structure to be protected or the source of current, burying the sources or the structure to be protected, applying cathodic protection, or using sacrificial targets in conjunction with the structure being protected.

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[2]Alternating current (AC) common to routine business and household electrical supply does not cause electrolytic processes as does DC; hence, metals are not plated into surrounding soils.

Microbial corrosion. Corrosion developing consequent to biological activity is frequently linked to bacteria and fungi or their by-products, and can occur because of attacks on metal or protective coating by acid by-products, sulphur, hydrogen sulphide or ammonia. These biologically-linked processes frequently result from a direct interaction between the microbes and metal which sustains attack. Preventing microbial-induced corrosion may be accomplished by selecting resistant materials and controlling exposure (e.g., remove nutrients from the environment). Depending on the engineering application, biocides or maintaining cleaning schedules may be incorporated into system operation, and reduced microbial-initiated corrosion may be realized. Again, cathodic protection may be effective in stemming corrosion linked to microbial processes.

Intergranular corrosion. Intergranular corrosion occurs as a preferential attack at a metal's crystal-grain boundary, and is caused by physicochemical differences between the centers and edges of the grain. Intergranular corrosion may be avoided by selecting stabilized materials for use in construction and by controlling heat treatments, e.g., avoiding extreme temperatures linked to initiating events.

Concentration-cell corrosion (crevice corrosion). Concentration-cell or crevice corrosion occurs if two areas of a component, lying in close proximity, present marked concentration differences for corrosive reactants, e.g., oxygen may occur at marked concentration differences along a crevice, and a differential aeration cell is set up which yield increase corrosion in with less oxygen-rich region. Crevice corrosion may be an inadvertent outcome of construction activity and may be reduced by avoiding sharp corners and stagnant areas ("dead space"), by using sealants to minimize crevices that promote concentration-cell corrosion, by using welds instead of bolts or rivets, and by selecting resistant materials.

Thermogalvanic corrosion. Temperature changes can alter a material's rate of corrosion, e.g., an engineering rule of thumb is a 10°C rise doubles the corrosion rate. If one part of component is hotter than another, the difference in the corrosion rate is accentuated by the thermal gradient between them. Initiating local corrosion occurs in a zone between the maximum and minimum temperatures, which may contribute to further corrosion beyond the originating site. Prevention or control of thermogalvanic corrosion relies on reducing thermal gradients or on supplying a coolant to offset temperature differences during the system's design and construction.

Corrosion caused by combined action. Any of the categories of corrosion briefly characterized may act in combination, e.g., corrosion may be accelerated by the action of fluid flow during pressure transients, especially if zones in the transmission system are periodically stressed under nominal operation. Protective layers and corrosion products of the metal may be continually attacked and material removed, exposing fresh metal to corrosion. Overall, prevention can be achieved by reducing the flow rate and turbulence, especially in problematic areas within the system. Depending on engineering constraints reflected in the system's design, protective coatings or linings may be used in areas susceptible to corrosion, and hydraulic design should avoid sudden changes of direction, e.g., in piping systems, to reduce turbulent flows and streamline fluid flow.

Corrosion and fatigue interactions. The combined action of cyclic stresses and a corrosive environment reduce the life of components below that expected by the action of fatigue alone. For example, SCC results from the combined action of a static tensile stress and corrosion, and yields cracks in stressed materials. Frequently, SCC leads to component failure, although it may be prevented or failures minimized by reducing the overall stress level and designing out stress concentrations, by selecting materials that are relatively resistant to the environment, and by designing system to minimize thermal and residual stresses. As with other corrosion processes, use of protective coating countermeasures is a common engineering solution to address system aging processes linked to corrosion. Similarly, fretting corrosion is associated with motion between contact surfaces, e.g., a stick-slip action, that frequently causes breakdown of protective films or welds that allow corrosion mechanisms to operate. Engineering solutions that minimize fretting corrosion range from simple lubrication or surface treatments to reduce wear and increase coefficient of friction to increasing load to stop motion.

Hydrogen damage. Hydrogen atoms and hydrogen ions can penetrate most metals, and by various mechanisms, embrittles a metal (especially in areas of high hardness), causing blistering or cracking, especially in the presence of tensile stresses. Hydrogen embrittlement is countered by using resistant or hydrogen free material, removal of hydrogen from metals during their manufacture, or by avoiding sources of hydrogen such as cathodic protection and certain welding processes.

3.2.1.1 Chemistry of corrosion. Corrosion reactions, e.g., in steel and iron, are commonly electrochemical in nature, and tuberculation is the most frequently encountered process exhibited in corrosion. Tubercles are mounds of corrosion product that cap localized regions of metal loss.

Internally, tubercles may obstruct pipes, leading to diminished flow and increased pumping costs. Tubercles form on steel and cast iron when surfaces are exposed to oxygenated waters. Soft waters with high bicarbonate alkalinity stimulate tubercle formation, as do high concentrations of sulfate, chloride, and other aggressive anions. Tubercles, however, are more than amorphous deposits of corrosion products. Tubercles are highly structured, and their growth is highly related to structure.

Incipient growth. In oxygenated water of near neutral pH and at or slightly above room temperature, hydrous ferric oxide [Fe $(OH)_3$] forms on steel and cast irons. Corrosion products are orange, red or brown colored and are the major constituent of rust. The rust-colored layer shields the underlying metal surface from oxygenated water, so oxygen concentration decreases beneath the rust layer. More reduced forms of oxide are present beneath the rust layer. Hydrous ferrous oxide ($FeO \cdot nH_2O$) as ferrous hydroxide [Fe $(OH)_2$] occurs next to the metal's surface. A black, magnetic hydrous ferrous ferrite layer ($Fe_3O_4 \cdot nH_2O$) can form between the ferric and ferrous oxides. These layers are shown schematically in the Figure 3-1. The topmost layer is orange and brown, whereas the underlying layers are usually black. As rust accumulates, oxygen migration is reduced through the corrosion product layer. Regions below the rust layer become oxygen depleted. An oxygen concentration cell starts to develop. Tubercles are initiated when corrosion becomes concentrated into small regions beneath the rust.

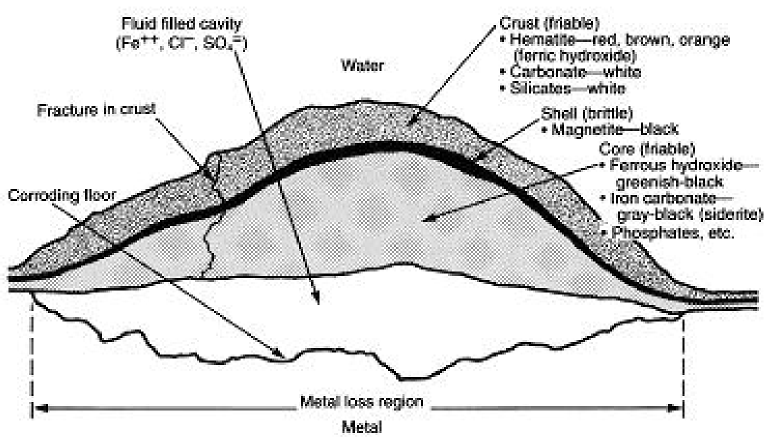

Figure 3-1. The typical features of a tubercle, showing chemical compounds and morphology. [NACE Corrosion/91, paper 84; H. Hero, Nalco Chemical Co.]

Structure and chemical composition. All tubercles have five structural features in common: outer crust, inner shell, core material, fluid-filled cavity, and corroded floor, with typical reactions occurring within zones of a tubercle, as briefly considered below (Figure 3-2).

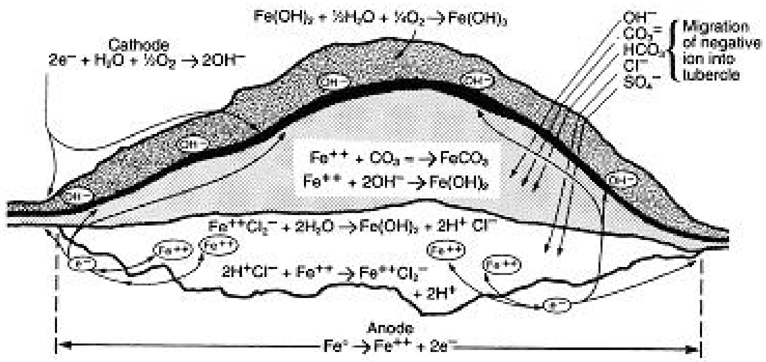

Figure 3-2. Typical chemical reactions occurring within a tubercle. [NACE Corrosion/91, paper 84; H. Hero, Nalco Chemical Co.]

The outer crust is composed of rust (hematite), precipitate, and settled particulate. If treatment chemicals have been incorporated into corrosion control programs, these may also deposit preferentially atop tubercles in response to associated corrosion, e.g., zinc and phosphate commonly occur when zinc phosphate has been used as an inhibitor. Silicates also can be found in conjunction with associated treatments. High concentrations of carbonate may be found in the crust, which is indicated by effervescence upon exposure to a few drops of acid.

The outer crust. A friable outer crust forms atop the tubercle. The crust is composed of ferric hydroxide (hematite), carbonates, silicates, other precipitates, settled particulate, and detritus. Ferrous ion and ferrous hydroxide generated within the tubercle diffuse outward through fissures, where they encounter dissolved oxygen. Ferric hydroxide is produced and precipitates atop the tubercle as in Reaction 1. In the crust:

$$Fe\,(OH)_2 + \tfrac{1}{2}\,H_2O + \tfrac{1}{4}\,O_2 \rightarrow Fe\,(OH)_3 \qquad (1)$$

The inner shell. Just beneath the outer crust a brittle, black magnetite shell develops. The shell separates the region of high dissolved-oxygen concentration outside the tubercle from the very low dissolved-oxygen regions in the core and fluid-filled cavity below. The shell is mostly magnetite and thus has high electrical conductivity. Electrons generated at the corroded floor are transferred to regions around the tubercle and to the shell, where cathodic reactions produced hydroxyl ion, locally increasing pH. Dissolved compounds with normal pH solubility, such as carbonate, deposit preferentially atop the shell where pH is elevated as in Reaction 2 within the shell:

$$e + H_2O + \frac{1}{2} O_2 \rightarrow 2OH \qquad (2)$$

The core. Friable core material is present beneath the magnetite shell. The core consists mostly of ferrous hydroxide formed by Reaction 3

$$Fe^{++} + 2OH \rightarrow Fe\ (OH)_2 \qquad (3)$$

The hydroxyl ions migrate inward, attracted by the positive charge that is produced by the ferrous ion generated near the corroding surface. Other anions such as carbonate, chloride, and sulfate also concentrate beneath the shell. Carbonate may react with ferrous ions to form siderite ($FeCO_2$) as in Reaction 4.

$$Fe^{++} + CO_3 \rightarrow FeCO_3 \qquad (4)$$

Other compounds, including phosphates, may be found within core material, depending on quality of material, e.g., treated water, being moved via pipeline.

Within the cavity. A fluid-filled cavity is sometimes present beneath the core. The cavity may be huge or small. The cavity may result, in part from acidic conditions internally. Chloride ions tend to migrate into this cavity to maintain a charge balance relative to the metal ions forming on the floor of the tubercle. Hydrolysis of the chlorides results in acidic conditions, which may prevent precipitation of oxides and hydroxides inside the tubercle.

The corroding floor. A localized corroded region is always present beneath the tubercular mound. The depression is usually much broader than it is deep, forming a shallow dish-shaped bowl. Iron dissolves, forming ferrous ions according to Reaction 5

$$Fe \rightarrow Fe^{++} + 2e \qquad (5)$$

If chlorides are present internally acidity increases due to hydrolysis, the floor of the core boundary will be characterized by Reaction 6

$$Fe^{++} + 2(Cl^{-}) + 2\ H_2O \rightarrow Fe(OH)_2\downarrow + 2H^{+}Cl \qquad (6)$$

and near the corroding floor Reaction 7

$$2H^{+}Cl + Fe^{++} \rightarrow Fe^{++}2\ (Cl) + 2H^{+} \qquad (7)$$

Hence, acidity will become pronounced, as a readily hydrolyzable anion such as chloride is present. Similarly, sulfate may accelerate attack by depressing internal pH.

Locations of tuberculation. Tubercles occur on non-stainless steels, and some cast and ductile irons, depending on their compositions. When these material's surfaces contact oxygenated water or other aggressive fluids or soil environments, corrosion occurs as a "growth process" dependent on moisture at interfacial surfaces. In water transmission systems, common components that suffer tuberculation include, e.g., any water system piping, pumps and pump components, storage tanks, and attachments (such as bolts), fittings, and sheet metals associated with constructed environment. Any uncoated or untreated or unprotected steel or iron component may be attacked, if it contacts oxygenated water or other aggressive anions for a prolonged period. Once corrosion processes have been initiated, formation and deposition of tubercles progresses, often times at increased rates, depending on materials and environmental conditions. Regions of a system where foreign material accumulates are common tubercle breeding grounds, e.g., stagnant or low-flow areas promote tubercle growth.

The relationship between flow and tubercle growth varies, e.g., low flow may stimulate growth, but zero flow (so that water contacting surfaces contains no oxygen) stops attack. If the flow is high, turbulence may dislodge incipient tubercles. Thus, pump impellers and other apparatuses experiencing severe turbulence almost never show tubercular growth unless they have been out of service for an extended period.

Critical factors. Dissolved oxygen is critical to tubercle growth. If dissolved oxygen concentration is very low, tubercular growth is reduced. Oxygen-saturated waters, however, are not required for growth, since near-stagnant systems often experience severe corrosion. In waters containing no dissolved oxygen, growth associated with oxygen-concentration-cell action ceases, since the driving force for tubercle growth is differential aeration.

Tubercles form under both high-flow and low-flow conditions. Flow directly influences tubercle morphology. When flow is great, tubercles elongate in the direction of the flow. Flow also affects growth by replenishing dissolved oxygen, aggressive anions, chemical inhibitors, and suspended particulate, e.g., sloughed from inner pipe walls. If flow is very high, turbulence will dislodge tubercular structures.

Biological interactions are poorly characterized with respect to the role that organisms play in tubercle development. Given observations that tubercles may form in superheated boilers during idle periods, it appears microorganisms do not have to be present for tubercle formation. Large numbers of microorganisms, however, colonize tubercles, although the extent that such organisms influence tubercular development is poorly characterized. Sulfate-reducers and acid-producing bacteria probably accelerate attack.

Aggressive anions such as chloride, sulfate, and other aggressive anions occurring in high concentrations in water stimulate tubercle growth. Very high concentrations of chloride and sulfate can be found internally in many fast-growing tubercles. Activity characteristic of tubercle formation and development enhance tubercle growth, e.g., hydrolysis produces acidic conditions internally and stimulate growth. As bulk water pH falls, tubercle numbers and size tend to increase, yet at sufficiently low pH, precipitates and oxides cannot form and tubercular structures cannot exist.

Tubercles are generally simple to observe, and commonly occur as friable brown and orange nodular encrustations on steel and iron water system components are almost always tubercles. Careful analysis can provide considerable information concerning growth, chemical composition, and associated metal loss. When dry, tubercles are usually brittle and can be crushed by gentle pressure with a finger. Tubercle caps can be dislodged whole with a hard implement such as a knife blade. The physical strength of the tubercle is related to the thickness of the magnetite shell and densities of crust and core material. Harder, denser tubercles usually grow at a slower rate than lower-density tubercles. Thin magnetite shells are usually indicative of fast growth, but are indicative of unsustainable development. The presence of multiple magnetite shells may indicate successive fractures in fast-growing formations. Ferrous species spew out of a fractured shell and are quickly oxidized to form a new ferric hydroxide crust. Beneath the new crust, another magnetite shell forms. As tubercles age, their internal structure and outer morphology are altered.

Tubercles may be very large [up to 6-in. (15cm.) diameter], and the amount of metal loss is usually much less than the accumulated corrosion product and deposit might suggest. The average tubercle density when dry may be less than 1 g/cm³. Hence, tubercles occupy much larger volumes than the metal loss they cap. Tubercle height may be from 5 to 30 times as great as he metal-loss depth below. The depth of metal loss below a tubercle can be roughly estimated using the above stated rule of thumb. Corrosion exceeding 50 mpy locally is severe; average corrosion rates of about 10-20 mpy beneath active tubercles are typical.

3.2.1.2 Corrosion control. Corrosion will be the most likely cause or contributing cause to failures in water transmission and distribution networks, especially following a system's start up and entry to useful life. Depending on its quality, water will vary in its corrosivity with respect to interactions with metal components in the system, e.g., pumps, pipes, gates, and valves. For example, rust and tuberculation of DIP and storage reservoirs may diminish system performance, e.g., tuberculation can dramatically increase the friction loss and reduce the carrying capacity of a transmission pipeline. Carbon dioxide (CO_2) dissolved in water will react to form carbonic acid (H_2CO_3) which contributes to corrosion, as does dissolved oxygen, especially if water alkalinity is low. Water corrosivity is also influenced by relationships between the pH and the alkalinity (see, e.g., Peabody 2001, Roberge 2000). Buried structures such as pipes are invariably exposed to corrosive soil environments which must be considered early in engineering design efforts anticipated as outcomes of our preliminary analysis.

Coatings and Lining Systems. External coatings and internal linings extend the service life of pipelines by minimizing leaks due to corrosion. Hence, both external and internal countermeasures are incorporated into pipeline design, since each means of control addresses different corrosive environments influencing the long-term service life of the system, e.g., internal lining would not mitigate external corrosion activity which could continue unimpeded in the absence of external coatings or wrappings of offset corrosive environments associated with soils and backfill. Internally lined and externally coated pipes control corrosion of ferrous components in the pipeline system. Pipe coatings and linings in concert with cathodic protection are considered an economical solution to both external and internal corrosion. For example, cement mortar lining is routinely used to control internal corrosion in pipelines relying on ferrous pipe, and in both new installation and in rehabilitation of existing service lines, buried piping will be cleaned and lined with cement or other materials as appropriate to a specific application.

External coatings. External countermeasures to corrosion in a pipeline system must consider native soils in the area and fill materials used during installation. The use of select, non-corrosive material (such as sand or limestone) for bedding and backfill represents one countermeasure commonly incorporated as“trench improvement” in constructing water transmission and distribution systems. Trench improvement generally provides good structural support and helps delay the onset of corrosion activity, in part by offsetting stresses associated with loads experienced under nominal operation. However, trench improvement does not provide long-term protection to the pipe, particularly in highly aggressive soil environments. Water permeation through native soils immediately adjacent to the trench provides moisture to backfill over time, and potentially initiates corrosive events adversely affecting buried pipe and fittings. Thus, trench improvement is part of corrosion control that complements practices that apply external coatings or wraps to pipe during the installation process. Polyethylene encasement is the most frequently relied upon as an external coating, most often as a pipe wrap, and is an effective method for corrosion prevention of ferrous pipe. Standards specify materials and installation practices for pipeline installation, e.g., pipe sections may be specified with a dielectric coating system consisting of machine applied, three layer polyethylene spiral tape wrap system conforming to AWWA Standard C214, and pipe fittings, specials and field joints would be similarly specified with a dielectric coating system consisting of a three layer polyethylene tape system conforming to AWWA C209.

Linings. Complementary countermeasures provide for corrosion control for internal environments common to water transmission and distribution pipelines. In water transmission and distribution systems, pipelines and other structures are routinely coated with interior lining systems of cement mortar or epoxy materials. Pipelines and other structures routinely are coated with interior lining systems to isolate the substrate from corrosive internal environments, e.g., cement mortar lining of pipe. Along with technical advances in materials used in manufacture of pipes, research on lining requirements for pipe and fittings has resulted in practices for installation of linings to meet many different applications. Several types of linings are available, the most common being cement mortar lining. Pipe and fittings may be lined, most often specified by AWWA C104 for cement-lined pipe and fittings, AWWA C110, C115, or C151 for asphaltic-lined pipe, or fusion-bonded epoxy lining for 4"-16" Fastite fittings, following AWWA C116. The principal standard covering cement mortar lining is ANSI/AWWA C104/A21.4.

Cement mortar lining. Cement-mortar linings have been successfully used to protect the interior of ferrous pipe and fittings for over 80 years. In general, cement linings of various formulations prevent tuberculation by creating high-pH microenvironments at the pipe wall. These alkaline pH conditions serve as a barrier to the potentially corrosive conditions associated with water being conveyed through the system. In this brief overview of cement mortar systems as corrosion control measures in pipe, DIP and ST pipe are considered jointly as ferrous pipe, although future technical analysis must address differences between the two materials that preclude the same surface preparation and application of coatings.

Physical properties of ferrous materials such as those characteristic of DIP change relatively little with time, although age-related changes in structural material associated with external and internal corrosion will undoubtedly affect the structural integrity of the pipe. Cement-mortar linings and special linings have eliminated or at least reduced concerns associated with internal corrosion, especially in new installations. Soils vary geographically at varying spatial scales with respect to their corrosivity, and final route will undoubtedly rely on, e.g., soil evaluation procedures outlined in Appendix A of the ANSI/AWWA C105/A21.5 Standard, "Polyethylene Encasement for Ductile-Iron Pipe Systems." If soils are corrosive, polyethylene encasement is the corrosion protection method normally recommended by the, e.g., Ductile Iron Pipe Research Association (DIPRA) and various manufacturers of DIP. If soils are non-corrosive when tested in accordance with Appendix A of ANSI/AWWA C105/A21.5, or if it is determined corrosive and the pipe is encased with polyethylene in accordance with the standard, ferrous pipe such as DIP could have a life expectancy of more than 100 years. If ferrous pipe is installed in aggressively corrosive environments without protection, its life expectancy would mainly be a function of that environment. To minimize atmospheric oxidation of aboveground ferrous pipe, asphaltic coating is applied in accordance with ANSI/AWWA C151/A21.51 may be incorporated into system designs, although when soils are determined to be corrosive by procedures detailed in Appendix A of ANSI/AWWA C105/A21.5, polyethylene encasement in accordance with the AWWA C105 standard should be installed for corrosion protection.

Cement-mortar lining for ferrous pipe (e.g., DIP and ST pipe) and fittings for water service follows ANSI/AWWA C104/A21.4. Most pipe place in service is cement-lined, and provides improved flow characteristics and protection required against internal corrosion. Cement linings are satisfactory for temperatures up to 212˚F (for asphaltic seal coats, the lining is only adequate for temperatures up to 150˚F). Lining is applied centrifugally with the speed of rotation designed to produce a smooth waterway surface, minimal voids, yet retaining enough moisture for proper curing. Cement-lined pipe and fittings are consistent with ANSI/NSF Standard 61 for potable water contact. Flow tests on cement-lined pipe under varying service conditions have established that the Hazen-Williams flow coefficient remains as expected at about 140, and for cement-lined, large-diameter pipe flow coefficients much higher than 140 are achieved.

Characteristics of Cement Lining. When a cement-lined pipe is placed in service and filled with water, two reactions begin immediately. Initially, a gradual reduction in temperature differential between pipe and lining occurs, reducing thermal stresses in the lining. Subsequently, the lining absorbs water into pores of the cement and into the capillary channels of the calcium silicate gel that forms as part of the cement structure. Water absorption causes the lining to swell and contact the pipe wall throughout its perimeter, closing cracks initially present in the lining. The swelling process is relatively slow and may take several weeks before the lining achieves its maximum volume. After a period of exposure to contained water, autogenous healing occurs wherein the lining tighten against the pipe wall, any remaining cracks in the cement lining close, and the surfaces of the cracks actually re-bond. Cement linings tighten and heal while in service and provide the corrosion protection to the pipe and the high flow coefficients for which they were designed. Cement lining will withstand normal handling, and if repairs are required, standards have been developed in response to these events (see AWWA C104 which provides that damaged lining may be repaired, following prescribed repair procedures). The thicknesses and weights of cement lining varies with pipe length and diameter, as specified in ANSI/AWWA C104/A21.4, and is usually installed using centrifugal spraying applications originally developed for large-diameter pipe during the 1930s.

Other Pipe Linings. Pipe and fittings may be lined with other materials, including special cement linings (e.g., reinforced with fiberglass or other material), asphaltic lining (e.g., in accordance with AWWA C110, C115, C153, and C151), or fusion-bonded epoxy (in which case installation is compliant with AWWA C116).

Limitations of cement mortar and epoxy linings. Despite the wide application of cement mortar lining, problems have been reported for cement mortar lining, although many of those concerns are associated with its role in pipelines rehabilitation. Cement mortar is a non-structural mixture and provides little, if any, additional support to the pipes, especially if highly deteriorated (Habibian 1994). Lime leaching is also an issue of cement mortar lining, and is derives from chemical reactions derivative of the two most important cement components: tricalcium silicate ($3CaO \cdot SiO_2$) and dicalcium silicate ($2CaO \cdot SiO_2$). When cement is mixed with water to form a paste, a complex series of reactions occur in which the compounds hydrate, go into solution, then form new hydrated precipitates, as given by the following reactions:

$$2(3CaO \cdot SiO_2) + 6H_2O \rightarrow 3CaO \cdot 2SiO \cdot 3H_2O + 3Ca(OH)_2 \quad (1)$$
$$2(2CaO \cdot SiO_2) + 4H_2O \rightarrow 3CaO \cdot 2SiO \cdot 3H_2O + Ca(OH)_2 \quad (2)$$

Each of these reactions forms a hydrated calcium silicate ($CaO \cdot 2SiO2 \cdot 3H2O$), which is the basic gel structure of hardened cement paste. As a result of these reactions, appreciable quantities of lime— $Ca(OH)_2$ —are formed. These, and additional lime from the hydration of other cement compounds, are partially soluble and release hydroxide ions upon dissolution, as follows:

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^- \quad (3)$$

This reaction increases the water's calcium, pH, and alkalinity. Under the resulting alkaline conditions, the calcium ions may combine with carbonate ions in the water to form calcium carbonate at the lining surface. Calcium carbonate precipitate may coat the lining and block further lime dissolution, but if the cement comes into contact with aggressive water, low pH, or alkalinity, the $CaCO_3$ coating cannot form. Under these circumstances, lime may leach excessively from the mortar, leading to the ''lime leaching'' phenomenon. Lime leaching is a form of corrosion on the pipe lining and has received much attention in recent years. Douglas et al. (1996) has summarized research focused on the evaluation and remediation of this problem, given toxic inorganic constituents such as aluminum, barium, cadmium, and chromium tend to leach from cement mortar linings. These toxicants may pose public health hazards (see, e.g., Berend and Trouwborst 1999).

Epoxy linings also present trade offs that may not be accepted without further analysis. For example, epoxy resins are materials derived from a thermosetmatrix process and consists of an epoxy resin and a curing agent (Juska and Puckett 1997). The materials outstanding adhesion, good chemical resistance, and thermal stability make it widely accepted as an engineering material (Anand and Srivastava 1997), yet its long-term performance may be limited because these materials may degrade and lose strength with time (Klein and Rancombe 1985). Expoxy linings may also present downside issues related to water quality, since early work by Schoenen et al. (1981) observed that water transported via epoxy-lined pipelines displayed increased bacterial colony counts. If epoxy-lined pipes are characterized by a time-related increased susceptibility of microbial growth (bacteria, fungi, and protozoa), then epoxy lining of pipelines for potable waters may be held suspect.

While cement mortar linings are currently widely used in water transmission and distribution networks, depending on project designs, sufficient question may arise regarding the use of these materials. In part, these current data insufficiencies are captured in standards and practices currently available to guide installation and use of water systems once built. A simple listing in Table 3-2 and the sources included in Section 8 (Literature Cited and Bibliography) suggest guidance is available to identify strengths and weaknesses associated with these corrosion control and pipe installation practices summarized by American Society for Testing and Materials (ASTM), American Water Works Association (AWWA), American National Standard Institute (ANSI), and National Association of Corrosion Engineers (NACE).

Table 3-2. Illustrative list of standards and practices available for evaluating pipe coatings and linings

ASTM D1598 Standard test method for time-to-failure of plastic pipe under constant internal pressure. ASTM D15991 Standard test method for short-time hydraulic failure pressure of plastic pipe, tubing and fittings. ASTM D21221 Standard test method for determining dimensions of thermoplastic pipe and fittings. ASTM D21431 Standard test method for cyclic pressure strength of reinforced, thermosetting plastic pipe. ASTM D2837 Obtaining hydrostatic design basis for thermoplastic pipe materials. ASTM E4321 Standard guide for selection of leak testing method. ASTM E4791 Standard guide for preparation of a leak testing specification.
AWWA C104/A21.4-95, ANSI Standard for Cement-Mortar Lining for Ductile-Iron Pipe and Fittings for Water AWWA C205-95, Cement-Mortar Protective Lining and Coating for Steel Water Pipe - 4 in. (100mm) and Larger - Shop Applied AWWA C602-95, Cement-Mortar Lining of Water Pipelines in Place - 4 in. (100mm) and Larger
NACE RPO184-91, Repair of Lining Systems NACE RPO187-90, Design Considerations for Corrosion Control of Reinforcing Steel in Concrete NACE RPO288-94, Inspection of Linings on Steel and Concrete NACE RPO892-92, Linings over Concrete for Immersion Service NACE T6A59, Linings Over Concrete in Immersion Service NACE 6A187, Reinforced Polyester and Epoxy Linings

Evaluation and characterization of the corrosivity of the soil environment, and implementing corrosion control during the design process for new infrastructure ensures long-term service life. Following a comprehensive program of corrosion control allows water systems to be proactively managed, thus minimizing, e.g., tuberculation, loss of capacity and pressure, and water leakage, break and burst rates, and contribute to risk reduction measures targeted on biota transfer concerns. For example, corrosion countermeasures such as cement mortar lining will reduce internal surface irregularities in pipe and residual disinfectant will be more effective in controlling biofilms.

3.2.2 Corrosive soil. Metal pipe laid in acidic to highly acid soils may encounter serious corrosion problems from the outside as well as the inside. For example, if DIP is to be laid in corrosive soil, it should be wrapped with polyethylene or coated with other protective coating to prevent it from being damaged. A soil's corrosivity depends on texture, drainage class, extractable acidity and measures of either resistivity of a saturated soil paste or electrical conductivity of the saturation extract are critical to developing corrosion countermeasures, e.g., for buried pipes. Standard methods for determining these measures are routinely available from, e.g., NRCS, and should be incorporated into future engineering and geotechnical support efforts to gain higher resolution estimates of failures associated with corrosion-sensitive infrastructure.

As briefly detailed in the preceding discussion, soil corrosion results from a chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and/or its properties. In soils, corrosion occurs through the loss of metal ions at anodic areas on a structure. At the anode, the base metal is oxidized to form positively charged metal ions which combine with the negatively charged ions in the soil, with the subsequent formation of metal oxide corrosion products. At the cathode the surplus of electrons from the anode combine with positively charged hydrogen ions from the soil environment to form hydrogen and a passivating film on the metal surface.

Soil characteristics that influence the type and extent of corrosion of steel include aeration and permeability characteristics of the soil, soil acidity, dissolved salt content, and resistivity of the soil. Aeration and permeability are the primary attributes of soil that impact corrosion, since these factors control access of oxygen and water to the steel or iron surface. Aeration and permeability characteristics of the soil are dependent on physical characteristics such as particle size, particle size distribution, and specific gravity. Aeration also depends on the topography of the area, the depth to the water table, and the amount of rainfall. Corrosion occurs to a lesser degree in soils that are porous, have good drainage and an ample oxygen supply (e.g., sandy soils). Clay soils which tend to have high water retention, poor aeration, and poor drainage have significantly higher corrosion rates.

Corrosion by differential aeration can also result. For example if a structure or pipe passes through two soils that differ in oxygen permeability, a galvanic current flows from the poorly aerated surface (i.e., anode) to the aerated surface (i.e., cathode). Lower oxygen concentrations typically occur at the bottom of a buried steel structure where the soil is more compact and farther from the source of oxygen in the atmosphere. Thus the bottom of the buried structure is potentially more susceptible to corrosion. Oxygen concentration cells can form at random in backfilled soils due to the presence of rocks and other foreign materials. Poorly aerated soils are known to be corrosive to carbon steel and favor pit growth.

Soil acidity or alkalinity also factors into the corrosion response of a material in soil. Steel in an acidic environment (pH < 4) tends to corrode rapidly in a general or uniform mode. In a neutral to slightly alkaline environment (4 < pH < 10) pitting corrosion tends to predominate, becoming less aggressive as the pH increases. In alkaline environments (pH > 10), steel corrosion is minimal due to the stability of the passive oxide film on the metal surface. The most corrosive soils are those that contain large concentrations of soluble salts (e.g., chloride). The soluble salts result in soils that have low electrical resistivities. Resistivity measurements are readily attainable and yield measurements that trend well with corrosivity levels of the soil. Therefore, resistivity is the property most commonly used to approximate the aggressiveness of a soil. Table 3-3 and Table 3-4 list general characteristics of soils that should be used to identify corrosive risks associated with soils, and Table 3-5 summarizes the general relationship between soil resistivity and the corrosion of steel in soils. Backfilled soils and bedding used in conjunction with pipeline installation should be evaluated with respect to its corrosion potential, especially as that relates to its juxtaposition near the pipe and its serving as a "buffer" between the filled pipe trench and surround soil environment. Caution is urged for applying these classifications blindly, as aeration and soil acidity could also factor into the corrosive soil conditions. Additionally, resistivity measurements may vary over time due to changes in the moisture content of the soil.

Table 3-3. Guides for Estimating Risk of Corrosion Potential for Uncoated Steel (Exhibit 618-1 from USDA 2003)

Property	Limits		
	Low	**Moderate**	**High**
Drainage Class and Texture[1]	Excessively drained, coarse textured or well drained, coarse to medium textured soils; or moderately well drained, coarse textured soils; or some- what poorly drained, coarse textured soils	Well drained, moderately fine textured soils; or moderately well drained, medium textured soils; or somewhat poorly drained, moderately coarse textured soils; or very poorly drained soils with stable high water table	Well drained, fine textured or stratified soils; or moderately well drained, fine and moderately fine textured or stratified soils; or somewhat poorly drained, medium to fine textured or stratified soils; or poorly drained soils with fluctuating water table
Total acidity (meg/100g)[2]	<8	8-12	>12
Resistivity at saturation (ohm/cm)[3]	>5,000	2,000-5,000	<2,000
Conductivity of saturated extract (mmhos cm-1)[4]	<0.3	0.3-0.8	>0.8

[1] Based on data in the publication "Underground Corrosion," table 99, p. 167, Circular 579, U.S. Dept. of Commerce, National Bureau of Standards.

[2] Total acidity is roughly equal to extractable acidity (as determined by Soil Survey Laboratories Method 6Hla, Soil Survey Investigations Report No. 42, Soil Survey Laboratory Methods Manual, Version 4.0, November 2004).

[3] Roughly equivalent to resistivity of fine-and medium-textured soils measured at saturation (Method 8E1, Soil Survey Investigations Report No. 42, Soil Survey Laboratory Methods Manual, Version 4.0, November 2004). Resistivity at saturation for coarse-textured soil is generally lower than when obtained at field capacity and may cause the soil to be placed in a higher corrosion class.

[4] Method 8Ala, Soil Survey Investigations Report No. 42, Soil Survey Laboratory Methods Manual, Version 4.0, November 2004. The relationship between resistivity of a saturated soil paste (Method 8E1) and electrical conductivity of the saturation extract Method 8A1a), is influenced by variations in the saturation percentage, salinity, and conductivity of the soil minerals. These two measurements generally correspond closely enough to place a soil in one corrosion class.

Table 3-4. Guide for Estimating Risk of Corrosion Potential for Concrete (Exhibit 618-2 from USDA 2003)

Property	**Limits**[1]		
	Low	**Moderate**	**High**
Texture and reaction	Sand and organic soils with pH>6.5 or medium and fine textured soils with pH>6.0	Sandy and organic soils with pH 5.5-6.5 or medium and fine textured soils with pH 5.0 to 6.0	Sandy and organic soils with pH<5.5 or medium and fine textured soils with pH<5.0
Na and/or Mg sulfate (ppm)	Less than 1000	1000 to 7000	More than 7000
NaCl (ppm)	Less than 2000	2000 to 10,000	More than 10,000

[1] Based on data in the National Handbook of Conservation Practices, Standard 606, Subsurface Drain, 1980.

Table 3-5. Soil Corrosivity vs. Resistivity	
Resistivity, ohm-centimeter	**Corrosiveness**
Below 500	Extremely Corrosive
500 -1,000	Corrosive
1,000 -2,000	Moderately Corrosive
2,000 - 10,000	Mildly corrosive
Above 10,000	Progressively less corrosive

3.2.3 Material-related fatigue failures. Metal fatigue is a significant problem because it can occur due to repeated loads below the static yield strength, which can result in unexpected failures while in use. Because of the inevitable discontinuities in any engineering material, most metal fatigue, e.g., cracks, that initiate in any structure generally stems from discontinuities in highly stressed regions of the component. Failure may be due to the discontinuity, design, improper maintenance or other causes indirectly related to these factors.

Wear failure. Wear may be defined as damage to a solid surface caused by the removal or displacement of material by the mechanical action of a contacting solid, liquid, or gas. It may cause significant surface damage and the damage is usually thought of as gradual deterioration. While the terminology of wear is unresolved, the following categories are commonly used.

- Adhesive wear
- Abrasive wear
- Erosive wear

Adhesive wear has been commonly identified by the terms galling or seizing. Abrasive wear or abrasion is caused by the displacement of material from a solid surface due to hard particles or protuberances sliding along the surface. Erosion, or erosive wear, is the loss of material from a solid surface due to relative motion in contact with a fluid that contains solid particles. More than one mechanism can be responsible for the wear observed on a particular part.

Fatigue failures. In general, fatigue failure is a process that leads to material fracture under repeated or fluctuating stresses that are less than the tensile strength of the material. Fatigue fractures are progressive, generally initiated as minute cracks that grow under the action of fluctuating stress. There are three stages of fatigue failure: initiation, propagation, and final fracture.

The initiation site is minute, generally limited to 2 to 5 grains of material about an origin that is often linked to a stress point. The succeeding stage of propagation, or crack growth, extends the point of incipient failure parallel to the direction of shear stress. As repetitive loading continues, the direction of the crack changes perpendicular to the tensile stress direction. Once the original crack is formed, it becomes an extremely sharp stress concentration that tends to drive the crack ever deeper into the metal with each repeating of the stress. As such, failures linked to metal fatigue are caused by repeated cycling of the load and represent the outcome of progressive localized damage due to fluctuating stresses and strains on the material.

The most effective method of improving fatigue performance is to improve design to eliminate or reduce stress, avoid sharp surface tears resulting from punching, stamping, shearing, or other processes, prevent the development of surface discontinuities during processing, reduce or eliminate tensile residual stresses caused by manufacturing, and improve fabrication and fastening procedures

Stress corrosion cracking.[3] As noted briefly above, stress corrosion cracking (SCC) is the cracking of a material produced by the combined action of corrosion and tensile stress. This stress can either be applied (external load), or can be residual stress in the metal (e.g., due to production process or heat treatment). Failures associated with stress corrosion cracking are usually unpredictable, e.g., after a few years of trouble-free service, a metal can suddenly crack without warning or earlier deformation. Various types of SCC are distinguished either according to their mechanism (e.g., intergranular stress corrosion cracking [IGSCC] or transgranular stress corrosion cracking [TGSCC]) or according to the environment that causes the cracking (e.g., sulfide stress corrosion cracking).

SCC can proceed in either of two ways—cracks may propagate along the grain boundaries (IGSCC) or may run through the individual grains (TGSCC). Mechanisms will differ according to the materials and process involved, and may also differ for the various SCC phenomena in diverse environments. Surface tensile stress must be present to cause SCC, and not uncommonly involves residual fabrication stresses, e.g., welded joints, so inside-the-pipe inspections would concentrate on the heat-affected zones of the welds. Operating stresses may also be significant, and checks on highly-stressed areas are generally incorporated into inspection service. Stress corrosion cracks

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[3]Environmental cracking or environment-sensitive cracking are general terms that cover different SCC and hydrogen damage phenomena.

are generally finely structured, with many branches, and the material may be unattacked over most of its surface, while fine cracks are propagated through it. Fracturing typically occurs at an external load (far) below the yield strength of the metal.

Hydrogen embrittlement. When tensile stresses are applied to a hydrogen embrittled component it may fail prematurely, and hydrogen embrittlement failures are frequently unexpected, sometimes catastrophic. An externally applied load is not required as the tensile stresses may be due to residual stresses in the material, and threshold stresses to cause cracking may be below the material's yield stress. Tensile stresses, susceptible material, and the presence of hydrogen are necessary to cause hydrogen embrittlement. Residual stresses or externally applied loads resulting in stresses significantly below yield stresses can cause cracking. Failure can occur without significant deformation or obvious deterioration of the component, with very small amounts of hydrogen frequently leading to hydrogen embrittlement in high strength steels. Common causes of hydrogen embrittlement are pickling, electroplating and welding.

Liquid metal embrittlement. Liquid metal embrittlement is the decrease in ductility of a metal caused by contact with liquid metal. The decrease in ductility can result in catastrophic brittle failure of a normally ductile material, with only small amounts of liquid metal being sufficient to result in embrittlement. Welding and other heat treatments may contribute to liquid metal embrittlement under the appropriate circumstances. Liquid metal can not only reduce the ductility but significantly reduce tensile strength; thus, catastrophic failure may occur in the absence of deformation or obvious deterioration of the component. Intergranular or transgranular cleavage fracture are the common fracture modes associated with liquid metal embrittlement, although reduction in mechanical properties may be linked to decohesion which results in a ductile fracture mode reduced tensile strength.

Creep failure. While creep failure is generally expressed in systems operating under elevated temperatures, these processes may affect failures for some components in engineering designs developed once alternatives of choice are selected. Creep is a time-dependent deformation of a material while under an applied load that is below its yield strength. Creep most often occurs at elevated temperature, but creep of materials may occur at room temperatures, and is commonly different across the range of materials—metals, plastics, rubber, concrete—likely to be used in infrastructure built as part of any water diversion system.

Basics of Material Fatigue. Fatigue, and in particular, "cyclic fatigue," will challenge the integrity of pipelines. Physical testing of pipe and operating experience suggest fatigue due to pressure cycles will influence service life of pipe, depending on condition of pipe components and period in use. Metal and plastic subjected to repetitive or fluctuating stress will fail at a stress much lower than that required to cause fracture on a single application of load. Failures occurring under conditions of dynamic loading are called "fatigue failures," and are generally observed after a considerable period of service. Metal subjected to cyclic fatigue may fail under stress much lower than that required to cause fracture on a single application of load. Fatigue failure of steels in a corrosive medium is characterized by a marked reduction in endurance and absence of a virtual fatigue limit, with an increasing occurrence of corrosion-associated fatigue crack development contributing to diminished endurance. Water may accelerate fatigue crack development, and its effect tends to increase with decreasing load frequency (Shipilov 2005, Nishida 1992, Uhl 1992, Speidel 1984).

Fatigue failure may occur unexpectedly, resulting in a brittle-appearing fracture, with no gross deformation at the fracture. On macroscopic inspection, the fracture surface is usually normal to the direction of the principal tensile stress, displaying a fracture surface with a smooth region the initiating crack propagated through the section, and a rough region where the member failed in a ductile manner when the cross section was no longer able to carry the load. Frequently the progress of the fracture is indicated by a series of rings, or "beach marks," progressing inward from the point of initiation of the failure (see, e.g., Nishida 1992, Uhl 1992).

Three basic factors are common to fatigue failure across a wide range of materials:

- maximum tensile stress of sufficiently high value,
- large enough variation or fluctuation in the applied stress, and
- sufficiently large number of cycles of the applied stress.

In addition, the magnitude and duration of stress, corrosion, temperature, overload, material structure, residual stresses, and combined stresses contribute to conditions for fatigue.

S-N Curves and Stress Cycles. A statistical analysis of fatigue data is critical to the evaluation of cyclic stress and its role in fatigue failure. Engineering fatigue data is frequently presented by an "S-N curve," a plot of stress (S) against the number of cycles to failure (N). A log scale is generally used for N, with values of stress plotted as nominal stresses that are not adjusted for stress concentration (Figure 3-3). Most determinations of the fatigue properties of materials reflected reversed stresses applied to the material which yield mean stress equal to zero. S-N curves typically capture fatigue failure at high numbers of cycles (N > 10^5 cycles).

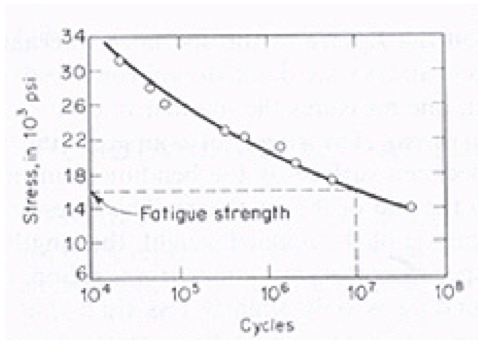

Figure 3-3. Illustration S-N curve.

A fluctuating stress cycle can be considered to be made up of two components, a mean stress, σ_m, and a variable stress σ_a (Figure 3-4). The range of stress σ_r, or the difference between the maximum and minimum stress in a cycle, is also critical to characterizing cyclic fatigue that may develop through time-in-service. Figure 3-4a illustrates a idealized cycle of stress of sinusoidal form wherein tension and compression contributions are completely offset about a mean σ_m equal to zero. Figure 3-4b illustrates a repeated stress cycle in which the maximum stress σ_{max} and minimum stress σ_{min} are not equal. Here, both phases of the cycle are characterized by tension, but a repeated stress cycle could also capture maxima and minima of opposite signs or both occur in the compression phase. Depending on operating conditions, a system may also present cyclic stress as depicted in Figure 3-4c, which illustrates a relatively complex stress cycle which reflects periodic and stochastic overloads.

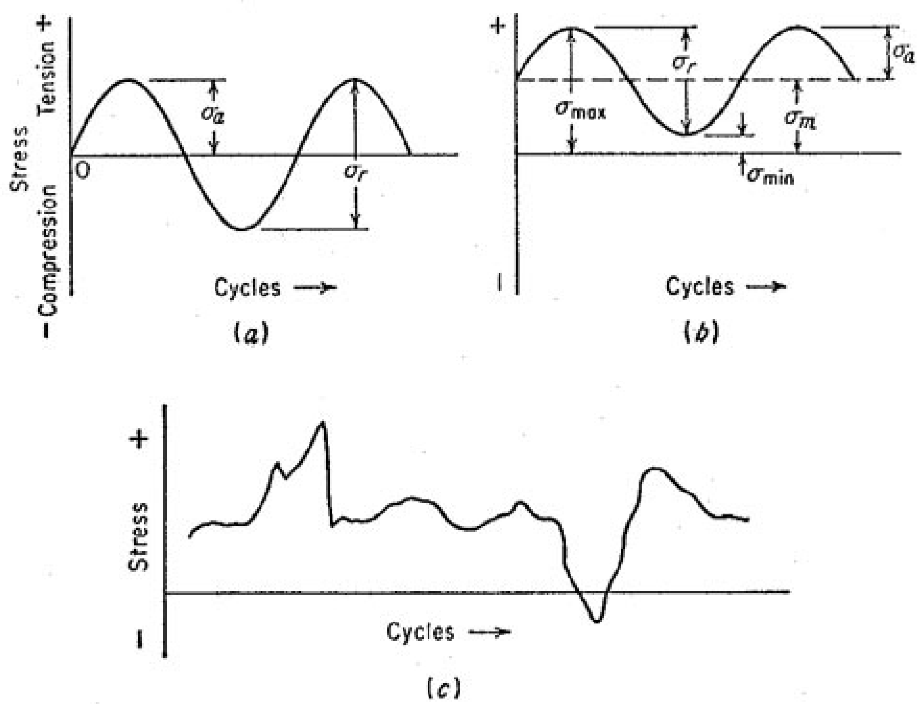

Figure 3-4. Typical fatigue stress cycles. (a) Reversed stress; (b) repeated stress; (c) irregular or random stress cycle (original figure available at http://www.key-to-steel.com/Articles/Art142.htm last accessed September 15, 2006).

Effect of Mean Stress and Cyclic Stress on Fatigue. Much of the fatigue data in the literature have been determined for conditions of completely reversed cycles of stress, $\sigma_m = 0$. However, field conditions are frequently encountered in engineering practice where the stress consists of an alternating stress superimposed upon some mean or nominal stress. Cyclic strain and cyclic stress both potentially influence the occurrence of failure within components of a system or in the system as a whole. For example, plastic deformations in materials such as PVC pipe are commonly not completely reversible, and structural changes to the material will occur during time-in-service. Depending on the initial state of the material being subjected to cyclic stresses and strain, age-related failures linked to, e.g., variable system loads hardening, may be observed in system or system components.

Cyclic fatigue in pipes as a risk factor for evaluating Action Alternatives. While cyclic calls to components within any water transmission system are potentially responsive to cyclic strain and stress, for this preliminary investigation the role of cyclic fatigue linked to system failure was primarily concerned with pipe materials envisioned as components in the water transmission system. Ferrous metals such as DIP or ST pipe are often characterized as having an infinite life related to cyclic fatigue when installed per existing standards. For example, DIP installed following ANSI/AWWA C150/A21.50 specifies a wall thickness that practically eliminates cyclic fatigue as a concern under most applications, with a design specification of internal pressure limits for wall stress set to 21,000 psi before allowances for service and casting are added. In the field, nearly all applications are characterized by stress usually much less than 21,000 psi, because of the extremely high pressure rating, conservative design, and casting practice of DIP. In the literature, cyclic fatigue limit for ductile iron has been reported to be between 28,000 psi and 35,000 psi (AWWA Standard 2002a).

Cyclic failure in PVC pipe, however, has been characterized. Working pressures assigned to various classes of PVC pressure pipes are generally based on burst regressions developed for pipes subjected to constant internal pressure (see, e.g., Moser and Kellogg 1994, Jeffrey et al. 2003, 2004). Pumped lines, however, frequently do not operate under constant pressure, which leads toward a form of failure due to material fatigue associated with stress fluctuations, if these occur with sufficient magnitude and frequency. PVC pipes are competent in handling pressure variance such as pressure fluctuations, e.g., a single pressure surge at twice working pressure for a short time period will likely be handled with the same factor of safety as the constant working pressure for fifty years. This capacity to handle short-term pressure stress is linked with the material's short-term tensile strength, which for PVC is much higher than the long-term rupture load (Uni-Bell 1991). Recommendations for PVC pipe in-service usually specify that peak design pressures should not exceed the nominal working pressure, however. If repetitive surges exceed about 100,000 occurrences during the life of the pipe, then cyclic fatigue becomes an increasingly critical risk factor, and an engineering fatigue design should be completed as part of the full design.

The type of PVC material used in pipe manufacture will influence the evaluation of failure. For example, if pipe made of oriented PVC (OPVC) is incorporated into a full design according to a static-pressure regressions, then the molecular orientation of the material will yield increased tensile strength in the hoop direction and subsequently confer increased capacity to operate at hoop stresses typically greater that of standard PVC pipes (see, e.g., Robeyns and Vanspeybroeck 2005). Recent work also suggests that current characterization of PVC's sensitivity to cyclic stress may be conservative. Jeffery et al. (2004) investigated long-term cyclic testing of PVC pipe to develop cyclic design methods for determining cyclic-fatigue failure life of PVC pipes. Through their studies, Jeffery et al. (2004) demonstrated that traditional methods applied in the testing process of predicting cyclic-fatigue failure were very conservative, depending on the diameter of the pipe being evaluated. For example, for 150mm PVC pipes, conventional methods predicted failures 322,000 cycles, but were not observed through 3.5 million cycles under laboratory conditions. Many pipes in the studies did fail due to extreme cyclic stresses, however, which lead to improved S-N fatigue diagrams for PVC pipes. While these designed laboratory analyses will undoubtedly be continued to address, e.g., similar S-N curves for larger diameter pipe, the results suggest that PVC pipes can withstand multiple small magnitude surges that are typical in municipal distribution systems.

Fatigue Response of PVC. These recent studies suggest that PVC pipe may currently be conservatively characterized with respect to its incidence of failure within water transmission systems. Nonetheless, the response of PVC to cyclic stresses must be considered, given the existing literature (see, e.g., Jeffrey et al. 2003, 2004, Robeyn and Vanspeybroeck 2005, Burn et al. 2005). Fatigue failure in PVC begins as a fatigue crack resulting from some initiation even, e.g., a flaw in the material matrix. The initiating event tends to occur toward the inside surface of the pipe where stress levels are highest, then increases with each stress cycle, dependent in part on the magnitude of the cycle. Through time, the crack penetrates the pipe wall, with the crack increasing in length from a few millimeters to a few centimeters along the longitudinal axis resulting in a leak, potentially a pipe break. In larger diameter pipes, or in pipe segments containing entrained air, the crack may reach a critical length prior to penetrating the wall and a pressure surge may result in a pipe burst. As noted earlier, the performance of OPVC under fatigue loading has been evaluated relative to standard PVC, and OPVC consistently operates at levels nearly twice that of standard PVC (see, e.g., Jeffrey et al. 2003, 2004, Robeyn and Vanspeybroeck 2005). In general, OPVC is characterized by greater resistance to fatigue at equivalent stress cycle amplitudes relative to standard PVC. In addition, OPVC also differs from standard PVC in crack propagation. Laboratory studies suggest that crack propagation in OPVC occurs at an angle to an introduced notch and not directly through the specimen, as a consequence of OPVC's molecular orientation. As such, the molecular orientation of the material tends to inhibit growth of a fatigue crack in the radial direction, thus lengthening the crack path before failure occurs. In contrast to these observations related to OVPC, Edwards et al. (2004) investigated fatigue in PVC pipe fittings. While fatigue resistance of PVC pipe fittings has often been assumed comparable to that of the corresponding pipe, Edwards et al. (2004) found that fatigue performance of PVC fittings is much lower than that of the pipe.

Multiple failure mechanisms. As the preceding overview of material failure suggests, existing data to guide material selection for components of a water transmission system varies across broad material classes (e.g., ferrous metal *v.* PVC) and within material classes (e.g., standard PVC *v.* OPVC). Regardless of materials of choice in the final design, material failures may result from multiple mechanisms or root causes, and a detailed failure analysis would be required to identify the appropriate root cause of the failure. Common causes of failure include misuse or abuse, construction and assembly errors, manufacturing defects, improper maintenance, design errors, improper material, improper heat treatments (e.g., welds), extraordinary operating conditions, inadequate quality assurance, inadequate environmental protection/control, and manufacturing discontinuities.

As an example of how failure analysis may benefit the selection of Action Alternatives to advance to full engineering design, this preliminary analysis has relied on tools commonly applied across a wide range of problems regarding system reliability. From a technical perspective, failure analysis is simply a way of characterizing the cause or causes of failure, and is accomplished by collecting and analyzing data, then considering outcomes of the analysis to eliminate or not alternative failure mechanisms linked with factors or system components that may have contributed to a specific component's or system's failure.

The range of tools applicable to this preliminary failure analysis includes, e.g., failure mode and effects analysis (FMEA) which has been the primary application used to examine potential failures in components or processes involved with proposed Action Alternatives. FMEA contributes to risk management by helping identify and mitigating threat-vulnerabilities associated with a system's operation. When applied within a HACCP framework, FMEA anticipates remedial actions that reduce cumulative impacts of life-cycle consequences (risks) from a systems failure (fault). As such, the preliminary failure analysis considered in this report complements the fault-probability tree approach applied to the analysis of risks associated with biota transfers potentially realized as collateral events of interbasin water diversions (USGS 2005a). As such, the current analysis of system failure illustrates connections between multiple contributing causes of failure and cumulative (life-cycle) consequences of biota releases.

3.2.3.1 Characterization of Infrastructural Pipe Materials. Materials used to make and join water transmission and distribution system piping have changed through time, as a consequence of advances in materials science and construction methods. The following section briefly summarizes background on materials frequently encountered in water transmission and water distribution networks, beginning with an overview of materials commonly used in the past as a setting for the materials identified for use in Action Alternatives.

Between the 1880s and the 1920s, most pipe laid in the US was manufactured from "pit" cast iron and was joined using rope and molten lead. Then, between the 1920s and 1960s "spun" cast iron predominated water project construction. Spun cast iron was stronger and more uniform than pit cast iron and allowed for thinner pipes. Cement lining and leadite joining compound (a plasticized sulfur cement) were also introduced during this period, and advances in pipe and joint technology have continued to advance. Cast iron pipe with leadite joints were replaced by cast iron pipes joined by leaded joints, which subsequently were replaced by flexible rubber gasket joints and ductile iron pipe. Polyvinyl chloride (PVC) and high density polyethylene (HDPE) piping emerged between the 1970s and 1990s, and as cast iron and ductile iron pipe have reached their end-of-service life, replacement pipe incorporates these materials when water demands are sufficiently met by pipe diameters less than, e.g., 24 inches.

Deteriorating water transmission and distribution system infrastructure has resulted in increased leakage, breaks, and bursts. Not surprisingly, as water transmission and distribution lines age, hydraulic capacity has been reduced (e.g., inner-pipe wall roughness significantly increases head loss) and increased biofilm growth is realized as companions to corrosion concerns characteristic of aging systems. And although less dramatic than pipe bursts, taste, odor and color complaints have been on the rise, especially in municipal systems. Consequently, age-related increased potentials for water quality degradation and increased health risks, including biota transfers, may be associated with failure events.

Most likely initiating events. Hydraulic transients through system life time serves to stress pipes, frequently at locations that are repeatedly challenged, e.g., near valves or pipe bends. Similarly, pipe joints regardless of their type (e.g., welded or collared) are stressed under system operation, which could potentially lead to bursts that partially or completely disable the system. Seasonal patterns in hydraulic stress, e.g., system operations during winter, may lead to pipe breaks linked to temperature which are well documented for iron pipes (see, e.g., Goulter and Kazemi 1988 on non-ferrous pipe, Andersland and Ladanyi, 2004, Mays 2000, 1999, Palmer and Williams 2003 and related in-journal discussion).[4]

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[4] Within water distribution systems, water main failures typically increase with freezing temperatures and are the result of differences in thermal expansion between water and iron. As

Internal corrosion of iron and steel piping occurs following a variety of mechanisms, as suggested in Section 3.2.1. Corrosion may be uniform or localized, with localized corrosion yielding spatially limited non-uniformities in the pipe, which may contribute to altered water quality within this pipe-reach and subsequent tuberculation processes. External corrosion may be predominately galvanic or electrolytic in origin, depending on the nature of surrounding soils and bedding materials used during construction. In rural installations, galvanic corrosion may predominate external corrosion processes, while electrolytic-based corrosion reflects stray current sources that initiate and drive the reactions illustrated in Section 3.2.1.1. While the brief overview of the corrosion process covered the spectrum of potential sources and mechanisms, most water transmission and distribution lines are predominately effected by processes linked to

- Pitting corrosion that occurs when protective films covering a metal break down.
- Microbiologically-induced corrosion, most often involving sulfate-reducing bacteria (SRB) which yields sulfides as respiratory products which serve as electrolytes necessary to the corrosion process.
- Soil corrosion reactions between the iron in pipes and soils with high electrical conductivity.
- Graphitic corrosion results from selective attacks to composite materials, e.g., between graphite flakes and iron matrix common to ductile iron and (depending on its fabrication) steel pipe, which through time preferentially corrodes one pipe constituent at a faster rate than other constituents of the composite.

Failures associated with material fatigue also applies to PVC and HDPE pipes that experience a reduction in strength over time. For example, studies focused on the performance and durability of the various types of pipes in Canadian municipal water utilities suggest that PVC pipes may be characterized by lower failure rates than DIP and ST pipe (see, e.g., Burn et al. 2005). Compared to DIP and ST pipe, PVC pipe is less chemically react to aggressive anions in water, and is also more resilient to impact stresses and earth movements. Moser and Kellogg (1994) conducted an evaluation of PVC pipe performance, and noted that water utilities have reported PVC pipe failures ranging from joint leakages to catastrophic failures during tapping. Some failures have been attributed to aging of the PVC material, while others suggest that pipe failures may reflect chemical permeation and variability of PVC composition among manufacturers. Overall, Moser and Kellogg (1994) observed that PVC pipe was increasing

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temperatures drop below 40°F, water begins to expand, while iron pipes continues to contract.

selected by water utilities because of the material's corrosion resistance, life expectancy, durability, and frictional head loss, in that order.

Regardless of material used in its manufacture, loss of pipe integrity may be linked to contamination associated with degraded pipe materials or release of contaminants—biological or chemical—through breaches in pipes or pipe joints. By-products of internal corrosion and the formation of tubercles contribute to taste, odor, and color problems and impart a disinfectant demand on distributed water. While transmission lines such as those proposed as Action Alternatives would not necessarily consider these water-consumption problems associated with aged pipe, corrosion by-products serve as habitat for microorganisms, e.g., as part of biofilms that develop in the transmission lines through time. Breaches in pipes or joints potentially realized consequent to external corrosion also provide entry points biota from adjacent soils, stormwater runoff, chemically contaminated soils, and exposure to animal wastes, which may unintentionally interact with water moving through a piped conveyance.

Pipe materials specified by Reclamation and presented in DEIS. DEIS (Reclamation 2005a) develops a focus on DIP, ST, and PVC, primarily because of economies of scale associated with alternative options for pipe materials. The size of pipe may play a role in which material is selected. For example, a cost-engineering break point between DIP and WSP has generally been found to be 30 to 36-inches in diameter (T. Hall, Bureau of Reclamation, personal communication), and PVC may be an engineering alternative-of-choice for pipeline reaches not requiring pipe diameters greater than 18 to 21 inches. If small diameter pipe is envisioned operating under high pressures, DIP or ST may be selected over PVC, if conditions do not allow selection of the plastic alternative. DIP or ST will likely be selected as pipe materials of choice for conveyance requiring diameters greater than 24 inches. Given the initial design outlined in Reclamation (2005c), the conveyance system's pipe system would likely include cathodic protection.

Although the type of pipe joint is critical to any failure analysis, no specific analysis of joint failure has been incorporated into this preliminary analysis. When system designs are fully specified, the contributions of joint failure to overall system risk should be incorporated into a detailed engineering analysis where integrated structural and hydraulic models may be applied to the evaluation. In the current investigation, pipeline failure was considered only through empirical pipe-break data and was relatively insensitive to failure mode (joint-dependent or joint-independent failure event). In general, gasketed joints will be used for both DIP and WSP, except in areas of restrained joints for WSP (see, e.g., Moser 2001, Antaki 1999, 1997, AWWA standards and manuals as applicable and listed in Section 8, this report).

3.2.3.2 Ductile iron pipe (DIP). Ductile iron pipe, as is cast iron, is highly regarded for its strength and load bearing capacity, which is reflected in DIP's frequent application to water transmission and distribution needs in the recent past. DIP is favored over CIP, which occurs most frequently as legacy infrastructure and has limited application, given DIP's greater strength and rigidity. DIP is heavy and when unprotected, is highly subject to corrosion from the inside and the outside. Depending on soil conditions, DIP should also be installed with cathodic protection to assure normal service life. A variety of joints are used to join individual sections of DIP in buried applications, with bell and spigot (O-ring push-on) and mechanical joint (MJ) connections the most common (see, e.g., Moser 2001, Antaki 1999, 1997, AWWA standards and manuals as applicable and listed in Section 8, this report). As with any of the pipe materials being considered for use in the Alternative Actions, installation (e.g., trenching and bedding) requires increased caution relative to other materials (e.g., PVC), since DIP does not flex and is relatively brittle (see, e.g., Moser 2001).

DIP is made in diameters up to 64 inches and are usually encased with polyethylene, cathodically protected, and cement-mortar lined to prevent corrosion. Underground sections are connected with bell-and-spigot joints; the spigot end of one pipe section is pushed into the bell end of an adjacent section. A rubber-ring gasket in the bell end is compressed when the two sections are joined, creating a watertight, flexible connection. Flanged and bolted joints are used for above-ground installations.

3.2.3.3 Steel pipe (ST) and Welded Steel Pipe (WSP). For given length, ST and WSP are lighter than DIP, and easier to handle and install due to the thinner wall thickness. Because both DIP and ST are considered flexible pipe, as opposed to rigid pipe, installation procedures are the same for both and requires the same trench widths and bedding. ST sections may be joined in a variety of ways. Sections of steel pipe may use gasketed joints, be welded together or joined with mechanical coupling devices. As a shared attribute with DIP, ST is susceptible to corrosion. Interior wetted surfaces of ST often have a cement-mortar or polyurethane lining to prevent any rusting that may lead to water quality deterioration. Exterior surfaces are coated with an asphalt product and encased with special tape or polyurethane to reduce corrosion due to contact with corrosive soils.

External corrosion and protection of DIP and ST pipe. Ductile iron has been commonly used as pipe material over the past 50 years, and by the late 1970's had replaced gray cast iron pipe in the marketplace. DIP is widely used in the transportation of raw and potable water, sewage, digester gas, slurries, and process chemicals. ST pipe has become increasingly competitive to DIP. ST is susceptible to corrosion, as is DIP and countermeasures must be incorporated into system design to assure nominal service life. Deterioration of underground DIP and ST pipes due to corrosion or mechanical failure is of increasing concern to users in both the private and the public sectors in North America and other countries. The primary concern relates to the increasingly large number of leaks, breaks, and bursts that have occurred in transmission and distribution systems as those systems age (see, e.g., AWWA 2001, American Water Works Service Company, Inc. 2002a, Shipilova and LeMay 2005, Boxall et al. 2004, Deb et al. 1995, NRC 2005a, Selvakumar et al. 2002).

3.2.3.4 Polyvinyl chloride pipe. There are a wide range of materials available to the manufacture of "plastic pipe," with polyvinyl chloride (PVC) being a popular pipe material for a range of applications. PVC pipe is lightweight, easy to install and repair, available in a wide range of sizes and strengths, although its maximum diameter is 48 inches which requires a mix of pipe materials in some systems envisioned in the DEIS. PVC is much less reactive to corrosive water and soil, and is not subject to galvanic corrosion or electrolysis. PVC pipe presents a relatively high rate of thermal expansion, which should be taken into consideration if the pipe is to carry water. PVC pipe must be installed with the same care as DIP and ST. Native backfill is specified for closing the trench for buried pipelines (see pertinent AWWA standards and manuals in Section 8, this report), along with select bedding materials around the pipe not unlike the bedding and backfill requirement for DIP and ST. These pipes are also corrosion-resistant, and their smoothness provides good hydraulic characteristics. Various coupling methods are capable with PVC, although transmission line segments would likely be joined with, e.g., bell-and-spigot compression-type joints. Valves and fittings available for PVC pipe are ferrous metal, some of which are direct bury and are protected from corrosion with polyethylene encasement and sarificial galvanic anodes. Stainless steel bolts are specified to extend the life of valves and fittings, and reduce the possibility of failure.

3.2.3.5 Soil conditions potentially influencing siting decisions. The type of soil and the general grading conditions at the building site are important factors in determining foundation construction details, such as footing design, backfill, and drainage. Soils are classified depending on several physical and engineering parameters including their grain size distribution, liquid and plastic limits, organic contents, drainage characteristics, frost heave potential, and swell potential. There are several types of classification systems: for example, the Unified Soil Classification System, the AASHTO Soil Classification System, and the U.S. Department of Agriculture (USDA) Classification System. The USDA (www.usda.gov) publishes soil maps that cover most counties and parishes within the U.S. These maps provide a general guide on the type of soils that may be found in any given region.

Soils can vary from rocks to loose sand or saturated clays. The selected engineering properties of soils are determined from several sources, including:

- published soil maps by the USDA Natural Resources Conservation Service and other government offices
- a review of borings from nearby sites
- geophysical exploration (e.g., seismic reflection and refraction, cross-hole testing, electrical resistivity soundings, etc.)
- in-situ testing (e.g., Cone Penetration Test, Standard Penetration Tests, Vane Shear Tests, etc.)
- soil borings at the construction site
- a test pit dug at the construction site

The USDA Natural Resource Conservation Service (NRCS) categorizes and describes soil types in four large groups depending on Unified Soil Classification System, their estimated engineering behavior, drainage characteristics, frost heave potential, and swelling potential (see Table 3-6). Suggested values for soil bearing capacities, undrained shear strength, and friction angles are presented in Table 3-7. These values are only estimated values to be used for light construction applications when other data are not available. It is also important to note that soil properties can vary significantly from one site to another and even within a single site.

Slope stability. Soil slope stability is an important design consideration that is often difficult to predict. A history of slope failures at or near the site is a strong indication of the presence of a problem, and further investigation and careful design considerations may be needed. A geotechnical engineer can predict whether slope failures are likely to occur at a particular site based on the slope angle, the characteristic drainage and seepage of the site, the shear strength properties of the soils (friction angle or undrained shear strength), and the external loads.

Table 3-6. Types of Soils and Engineering Characteristics

Soil Group	Unified Soil Classification Symbol	Soil Description	Drainage Characteristics[1]	Frost Heave Susceptibility[2]	Volume Change Potential Expansion[3]
Group I *Excellent*	GW	Well-graded gravel, gravel-sand mixtures, little or no fines	Good	Low (F1)	Low
	GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	Good	Low (F1) to Medium (F2)	Low
	SW	Well-graded sands, gravely sands, little or no fines	Good	Medium (F2)	Low
	SP	Poorly graded sands, gravely sands, little or no fines	Good	Medium (F2)	Low
	GM	Silty gravels, gravel-sand-clay mixtures	Medium	Low (F1) to High (F3)	Low

Table 3-6. Types of Soils and Engineering Characteristics

Soil Group	Unified Soil Classification Symbol	Soil Description	Drainage Characteristics[1]	Frost Heave Susceptibility[2]	Volume Change Potential Expansion[3]
	SM	Silty sand, sand-silt mixtures	Medium	Mekium (F2) to High (F3)	Low
Group II *Fair to Good*	GC	Clayey gravels, gravel-sand-clay mixtures	Medium	High (F3)	Low
	SC	Clayey sand, sand-clay mixtures	Medium	High (F3)	Low
	ML	Inorganic silts and very fine sands, rock flour, silty fine sands or clayey silts with slight plasticity	Medium	Very High (F4)	Low
	CL	Inorganic clays of low to medium plasticity, gravely clays, sandy clays, silty clays, lean clays	Medium	High (F3) to Very High (F4)	Medium
Group III *Poor*	CH	Inorganic clays of high plasticity, fat clays	Poor	High (F3)	High to Very High
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils	Poor	Very High (F4)	High

Table 3-6. Types of Soils and Engineering Characteristics

Soil Group	Unified Soil Classification Symbol	Soil Description	Drainage Characteristics[1]	Frost Heave Susceptibility[2]	Volume Change Potential Expansion[3]
Group IV *Unsatisfactory*	OL	Organic silts and organic silty clays of low plasticity	Poor	High (F3)	Medium
	OH	Organic sands of medium to high plasticity, organic silts	Unsatisfactory	High (F3)	High
	PT	Peat and other high organic soils	Unsatisfactory	High (F3)	High

Source: Table modified from the U.S. Department of Agriculture (http://www.usda.gov/).

[1] Percolation rate for good drainage is over 4 inches per hour, medium drainage is 2 to 4 inches per hour, and poor drainage is less than 2 inches per hour.

[2] After Coduto, D.P.(2001). Foundation Design. Prentice-Hall. F1 indicates soils that are least susceptible to frost heave, and F4 indicates soils that are most susceptible to frost heave.

[3] For expansive soils, contact a geotechnical engineer for verification of design assumptions. Dangerous expansion might occur if soils classified as having medium to very high potential expansion types are dry but then are subjected to future wetting.

Table 3-7. Engineering Properties of Soils

Soil Group	Unified Soil Classification Symbol	Bearing Capacity (psf)	Undrained Shear Strength[1] (psf)	Angle of Internal Friction (degrees)
Group I *Excellent*	GW	2,700-3,000	NA	38-46
	GP	2,700-3,000	NA	38-46
	SW	800-1,200 (loose)	NA	30-46 (loose to dense)
	SP	800-1,200 (loose)	NA	30-36 (loose to dense)
	GM	2,700-3,000	NA	38-46
	SM	1,600-3,500 (firm)	NA	28-40 (firm)
Group II *Fair to Good*	GC	2,700-3,000	NA	38-46
	SC	1,600-3,500 (firm)	NA	30-34 (dense)
	ML	2000	NA	30-34 (dense)
	CL	600-1,200 (soft) — 3,000-4,500 (stiff)	0-250 (soft) — 1,000-1,200 (stiff)	NA
Group III *Poor*	CH	600-1,200 (soft) — 3,000-4,500 (stiff)	250-500 (soft) — 2,000-4,000 (stiff)	NA
	MH	2000	1600	NA

Source: Table modified from the U.S. Department of Agriculture (http://www.usda.gov/), *FEMA Coastal Construction Manual* (http://www.fema.gov/), and Bardet, J. (1997). Experimental Soil Mechanics. Prentice-Hall.

[1] The undrained shear strength is also commonly referred to as cohesion in saturated clays.

psf = pounds per square foot NA = not applicable

3.2.4 Failure associated with earth movements.[5] Earthquakes and frost heaving are the most likely earth movement events considered in this preliminary failure analysis. The northern Great Plains is not particularly active with respect to earthquakes, and when these geological events occur, public interest is keen and well documented (see, e.g., Bluemle 2002 and citations listed, Footnote 5). However, limited seismic activity has occurred throughout the region. For example, in summer of 1968, an earthquake with an epicenter southwest of Huff, North Dakota occurred and sensed over a 3,000-square-mile area, including Bismarck and other central North Dakota communities. USGS National Earthquake Information Center (NEIC) has record a number of low-energy seismic events in North Dakota, Minnesota, and environs, with the most widely sensed earthquake occurring in late spring of 1909. That event had an epicenter near Avonlea, Saskatchewan, near the Montana-North Dakota-Saskatchewan border, and was felt throughout North Dakota and western Montana as well as in the adjacent Canadian Provinces. Earthquakes records are compiled by USGS NEIC which indicates a range of events have occurred in the region, including one in southeastern North Dakota in 1872; Pembina in 1900; three in the Williston area in 1915, 1946, and 1982; the Hebron area in 1927; near Havana in 1934; and the Selfridge area in 1947. Earthquakes centered near Morris, Minnesota were felt in southeastern North Dakota in 1975 and 1993.

While earthquakes would represent extreme events on the northern Great Plains, frost heaving commonly occurs during winters in the northern Great Plains. Damage from frost action results from the formation of segregated ice crystals and ice lenses in the soil and the subsequent loss of soil strength when the ground thaws. For example, frost heave damages highway and airfield pavements, but tends to be less of a problem for dwellings and buildings that have footings which extend below the depth of frost penetration. In cold climates, unheated structures that have

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[5]Further reading as noted in Section 8, but especially:
Bolt, B.H., 1988, Earthquakes, (3rd ed.): New York, W.H. Freeman and Company, 282 p.

Biek, B., 1997, Earthquakes in North Dakota, North Dakota Geological Survey Newsletter, Vol. 23, No. 1, pp 17-23. Bluemle, J.P., 1989, Earthquakes in North Dakota, North Dakota Geological Survey Newsletter, No. 6, pp 21-25.

Earthquakes in North Dakota, North Dakota Notes, North Dakota Geological Survey website: http://www.state.nd.us/ndgs/Earthquakes/earthquakes.htm

National Earthquake Information Center, United States Geological Survey: http://neic.usgs.gov/
United States Geological Survey, Earthquake Hazards Program: http://earthquake.usgs.gov/

concrete or asphalt floors can be damaged by frost heave. Driveways, patios, and sidewalks can heave and crack. The thawing of the ice causes a collapse of surface elevation and produces free water perches on the still frozen soil below. Soil strength is reduced. Back slopes and side slopes of cuts and fills can slough during thawing.

3.2.4.1 Earthquake history of North Dakota. No earthquakes of magnitude 5.0 or above (intensity V or above on the Modified Mercalli Scale) have occurred within North Dakota during historical times. Earthquakes centered in Iowa, Minnesota, Montana, and Nebraska, and a few Canadian tremors have been felt in the state. The first instrumentally located earthquake in the history of North Dakota occurred on July 8, 1968, when a magnitude 4.4 earthquake was felt over approximately 7,700 square kilometers of south-central North Dakota. Effects were noted at Bismarck, Fort Rice, Linton, Mandan, Menoken, and Moffit, with lesser intensity effects experienced at Almont, Flasher, Halliday, and Saint Anthony. Southeastern North Dakota experienced tremors on July 9, 1975, from a magnitude 4.8 earthquake located near Morris, Minnesota. Felt reports were received from Fargo and West Fargo, Casselton, Hankison, and Wahpeton.

North Dakota seismic hazards. To estimate earthquake risk a particular area, USGS NEIC has developed seismic risk maps for the US based on the probability that a particular seismic event of a certain energy value will occur within a specific time frame within a specified distance from a particular location is developed by USGS NEIC. Seismic hazards are generally considered by USGS NEIC in two ways. One, a seismic hazard for a particular area considers what the probability would be that an earthquake of a given magnitude would occur at a particular location of interest during a specified period of time. If one were to consider what the probabilities of an earthquake of magnitude 5.0 or greater (earthquakes of magnitude 5.0 or greater are generally considered to be of a destructive character) occurring within the next 1000 years (roughly 14 lifetimes) at a range of 50 km (around 31 miles) from each major North Dakota city we would find a less than 10% chance of experiencing this kind of an earthquake within the next 1000 years (Table 3-8). Wahpeton and Bismarck have slightly higher probabilities than other cities in North Dakota, and Williston has the highest probability, since that city is located near preexisting, deeply buried fault structures at the northwestern and southeastern boundaries of the state and on Precambrian basement rocks that have been related to historic earthquakes in North Dakota (Bluemle 1989).

Table 3-8. Geographic locations and their associated range of probabilities for experiencing an earthquake ≥ Magnitude 5.0 (see Bluemle 2002)

Probability ranges[1,2] of an earthquake greater than or equal to a Magnitude 5.0 event occurring within 1000 yrs and 50 km of selected North Dakota Cities

North Dakota City	Probability Range	Relative Ranking
Williston	0.30-0.40	1
Wahpeton	0.15-0.20	2
Bismarck	0.10-0.20	3
Fargo	0.06-0.10	4
Valley City	0.06-0.10	5
Minot	0.05-0.10	6
Grand Forks	0.06-0.08	7
Jamestown	0.06-0.08	8
Devils Lake	0.05-0.06	9
Rugby	0.05-0.06	10
Dickinson	0.04-0.06	11

[1]Values obtained from the USGS seismic hazard probability calculator.
[2]To provide a bit of perspective here, the probability range for the occurrence of a magnitude 5.0 earthquake within 1000 years and 50 kilometers of Los Angeles is 0.9-1.0 (or a 90-100% probability of occurrence).

Another way to characterize seismic risk is by way of ground acceleration presented as ground shaking hazard, which is the rate of horizontal ground motion for a particular area calculated from the frequency and number of previous earthquakes of various magnitudes and currently available information on fault-slip rates.[6] Compared to the rest of the US, North Dakota

[6]The "probability of exceedance" (PE) for any given site on any seismic hazard map reflects an estimated ground motion effect (or peak acceleration) at the location of interest for all the earthquake locations and magnitudes believed possible in the vicinity of that location. Each of these magnitude-location pairs is believed to occur at some average probability per year, with small ground motions being relatively likely while large ground motions are very unlikely. Beginning with the largest ground motions and proceeding to smaller, USGS NEIC adds probabilities until an estimate of total probability is derived, which corresponds to a given probability, *P*, in a particular period of time, *T*. The probability *P* comes from ground motions larger than the ground motion at which we stopped adding. The corresponding ground motion (peak acceleration) is said to have a *P* probability of exceedance (PE) in *T* years. The map contours the ground motions corresponding to this probability at all the sites in a grid covering the US. Thus the maps are not actually probability maps, but rather ground motion hazard maps at a given level of probability.

is well within the area with the lowest potential ground shaking hazard of 0-2% g (when an earthquake occurs the forces caused by ground shaking can be measured and expressed as a *%g* or the force of gravity at the surface of the earth; Figure 3-5). Low probabilities of ground

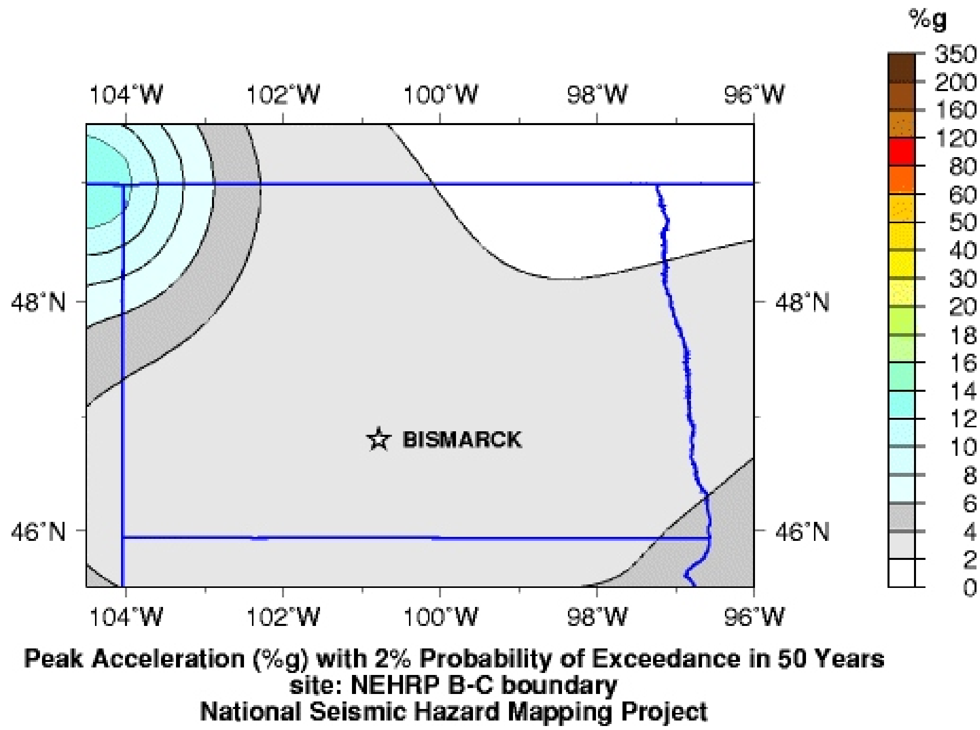

Figure 3-5. Seismic hazards in North Dakota reflected in peak acceleration values.

shaking hazards throughout the northern Great Plains simply reflects the distance from active seismic areas and major fault systems within the southeast central (New Madrid Fault immediately north of Memphis, Tennessee) and the western US (San Andreas Fault on west coast of California), and on the configuration of the region's Precambrian basement.

3.2.4.2 Earthquake History of Minnesota. Historically, seismic activity in Minnesota has been similar to that of North Dakota, although the number of earthquakes felt and their magnitudes are slightly greater in number. Historic records in USGS NEIC indicate that the first record of an earthquake in Minnesota was in 1860, but little, if any, data or information beyond anecdotal accounts are available. After the turn of the century, seismic activity compiled by NEIC indicates that seismic events occasionally ranged between magnitude 5 and 6, e.g., an earthquake in early September, 1917, occurred in central Minnesota. Several events located in the central and northern Great Plains have been felt within Minnesota's borders. A magnitude 7 earthquake centered in Illinois occurred in May, 1909 and affected parts of southeastern Minnesota. Relatively recent earthquake activity occurred in south-central Illinois in November, 1968 and a range of Intensity I-IV effects were noted in Minnesota at Austin, Glencoe, Mankato, Minneapolis, Rochester, and St. Paul. Current USGS NEIC seismic hazard maps for Minnesota display peak acceleration as *%g* that range similarly to those estimates for North Dakota (Figure 3-6).

Earthquakes originating in the northern Great Plains and western Minnesota are generally deeply buried in Precambrian strata. Few seismograph stations are located in the northern Great Plains, because it is geologically stable. A world-wide network of seismographs provides data to organizations such as USGS NEIC, but earthquakes with epicenters in central North Dakota and western Minnesota would only be detected at magnitudes greater than 3.3. North Dakota, western Minnesota, and Manitoba are considered as area of low earthquake probability, although tremors of magnitude less than 3.3 may be sensed locally in the absence of instrumental verification. Infrequent, small earthquakes may occur near or within the region, but it is unlikely they will cause any serious damage (Figure 3-7).

3.2.4.3 Earthquakes in Manitoba. Throughout Canada, the evaluation of regional seismic hazard is the responsibility of the Geological Survey of Canada. The seismic zoning maps prepared by the Geological Survey are derived from statistical analysis of past earthquakes and from advancing knowledge of Canada's tectonic and geological structure. On the maps, seismic hazard is expressed as the most powerful ground motion that is expected to occur in an area for a given probability level. Contours delineate zones likely to experience similarly strong of ground motions.

Seismic zoning maps, conceived to support national building codes, divide Canada into seven zones of ground motion, one map on the basis of probable ground velocity and the other according to acceleration. Velocity is given in meters per second; acceleration is expressed as a

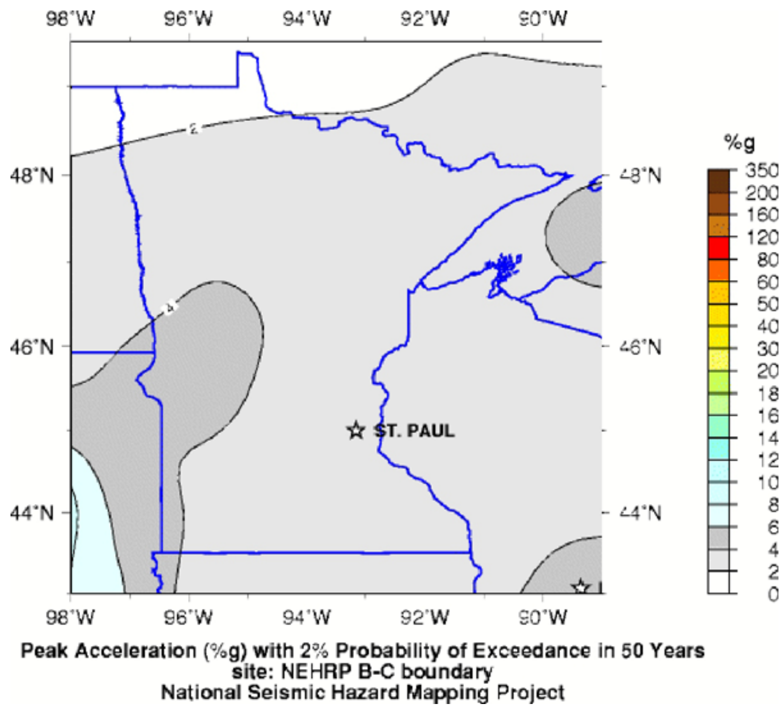

Figure 3-6. USGS National Seismic Hazard Map—Minnesota.

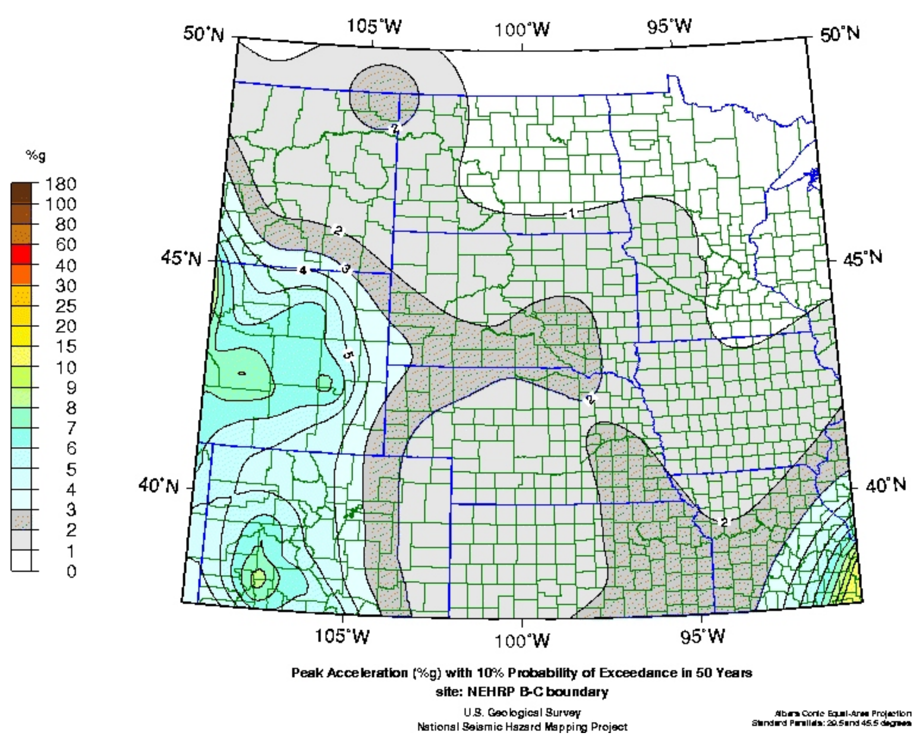

Figure 3-7. USGS National Seismic Hazard Map—Northern Great Plains.

fraction of gravity. Ground motion probability values are given in terms of probable exceedence, that is the likelihood of a given horizontal acceleration or velocity being exceeded during a particular period.[7] Most structures are designed for withstanding vertical forces, but the horizontal component of ground motion is critical to earthquake-resistant building design. The seismic hazard at a given site is determined from numerous factors. Canada has been divided into earthquake source regions based on past earthquake activity and tectonic structure. The relation between earthquake magnitude and the average rate of occurrence for each region is weighed, along with variations in the attenuation of ground motion with distance. Seismic hazards are calculated regionally and are based on all earthquake source regions within a relevant distance of the proposed site. The acceleration and velocity seismic zoning maps show levels of ground shaking over different frequency ranges: centered near 5 hertz (oscillations per second) for the acceleration map and near 1 hertz for the velocity map[8] (Figure 3-8 and Figure 3-9, respectively).

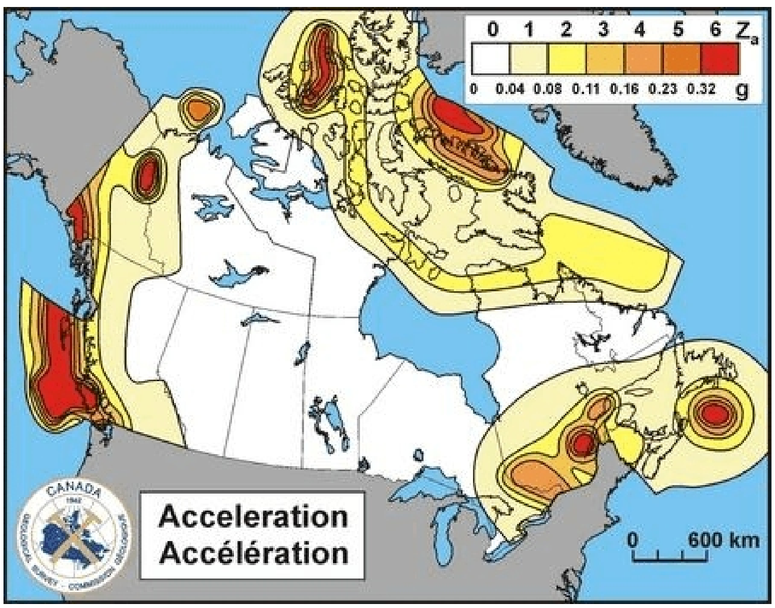

Figure 3-8. Seismic map—Canada wide—based on ground acceleration.

[7]The probability used in the National Building Code is 0.0021 per annum, equivalent to a 10-per-cent probability of exceedence over 50 years. This means that over a 50-year period there is a 10-per-cent chance of an earthquake causing ground motion greater than the given expected value.

[8]For additional detail see Heidebrecht, A.C., P.W. Basham, J.H. Rainer, and M.J. Berry, 1983, Engineering Applications of New Probabilistic Seismic Ground-Motion Maps of Canada, Canadian Journal of Civil Engineering, Vol. 10, pages 670 - 680.

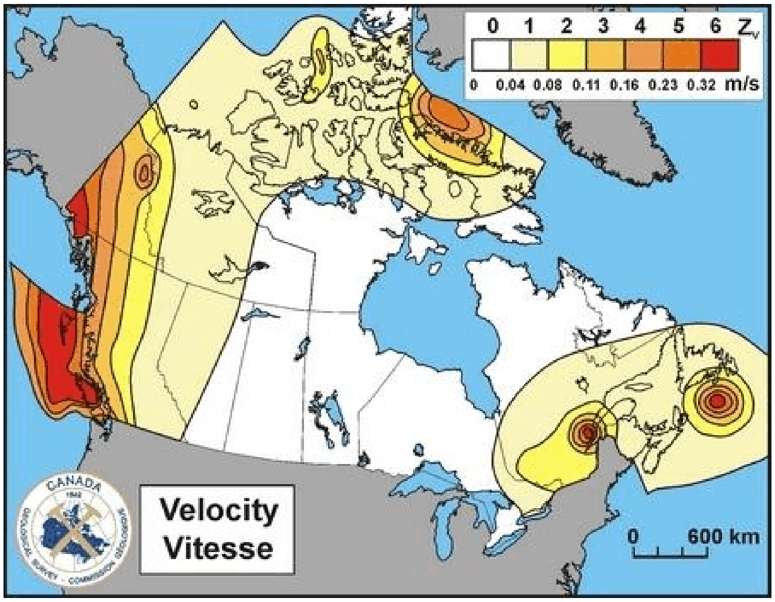

Figure 3-9. Seismic map—Canada wide—based on ground velocity.

3.2.4.4 Soil heave and frost action.[9] Potential frost action is the rating for the susceptibility of the soil to upward or lateral movement by the formation of segregated ice lenses. It rates the potential for frost heave and the subsequent loss of soil strength when the ground thaws. Soils are categorized into classes in regions where frost action is a potential problem (see Table 3-9).[10] The classes are low, moderate, and high as characterized

- Low, soils are rarely susceptible to the formation of ice lenses.
- Moderate, soils are susceptible to the formation of ice lenses, which results in frost heave and subsequent loss of soil strength.
- High, soils are highly susceptible to the formation of ice lenses, which results in frost heave and subsequent loss of soil strength.

Freezing temperatures, soil moisture, and susceptible soils are needed for the formation of segregated ice lenses. Ice crystals begin to form in the large pores first. Water in small pores or water that was adsorbed on soil particles freezes at lower temperatures. This super cooled water is strongly attracted to the ice crystals, moves toward it, and freezes on contact with them. The

[9] (see Section 618.29, USDA 2003).

[10](see Exhibit 618-5 in USDA 2003).

resulting ice lense continues to grow in width and thickness until all available water that can be transported by capillary has been added to the ice lense and a further supply cannot be made available because of the energy requirements.

Soil temperatures must drop below 0˚ C for frost action to occur. Generally, the more slowly and deeply the frost penetrates, the thicker the ice lenses are and the greater the resulting frost heave is. Figure 3-10[11] provides a map that shows the design freezing index values in the continental United States. The values are the number of degree days below 0˚ C for the coldest year in a period of 10 years. The values indicate duration and intensity of freezing temperatures. The 250 isoline is the approximate boundary below which frost action ceases to be a problem. Except on the West Coast, the frost action boundary corresponds closely to the mesic-thermic temperature regime boundary used in Soil Taxonomy. More information is provided in the U.S. Army Engineer School, Student Reference, 1967, Soil Engineering, Section I, Volume II, Chapters VI-IX, Fort Belvoir, Virginia.

Water necessary for the formation of ice lenses may come from a high water table or from infiltration at the surface. Capillary water in voids and adsorbed water on particles also contribute to ice lense formation; but unless this water is connected to a source of free water, the amount generally is insufficient to produce significant ice segregation and frost heave.

The potential intensity of ice segregation is dependent to a large degree on the effective soil pore size and soil saturated hydraulic conductivity, which are related to soil texture. Ice lenses form in soils in which the pores are fine enough to hold quantities of water under tension but coarse enough to transmit water to the freezing front. Soils that have a high content of silt and very fine sand have this capacity to the greatest degree and hence have the highest potential for ice segregation. Clayey soils hold large quantities of water but have such slow permeability that segregated ice lenses are not formed unless the freezing front is slow moving. Sandy soils, however, have large pores and hold less water under lower tension. As a result, freezing is more rapid and the large pores permit ice masses to grow from pore to pore, entombing the soil particles. Thus, in coarse-grained soils, segregated ice lenses are not formed and less displacement can be expected.

[11](see Exhibit 618-6 in USDA 2003).

Estimates of potential frost action generally are made for soils in mesic or colder temperature regimes. Exceptions are on the West Coast, where the mesic-thermic temperature line crosses below the 250 isoline, as displayed in Figure 3-10[12], and along the East Coast, where the soil climate is moderated by the ocean. Mesic soils that have a design freezing index of less that 250 degree days should not be rated because frost action is not likely to occur. The estimates are based on bare soil that is not covered by insulating vegetation or snow. They are also based on the moisture regime of the natural soil. The ratings can be related to manmade modifications of drainage or to irrigation systems on an on site basis. Frost action estimates are made for the whole soil to the depth of frost penetration, to bedrock, or to a depth of 2 meters (6.6 feet), whichever is shallowest. Table 3-9[13] is a guide for making potential frost action estimates. It uses the moisture regimes and family textures as defined in Soil Taxonomy.

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[12]see USDA 2003 (Exhibit 618-6).

[13]see USDA 2003 (Exhibit 618-5).

Table 3-9. Potential Frost Action (Exhibit 618-5 from USDA 2003)

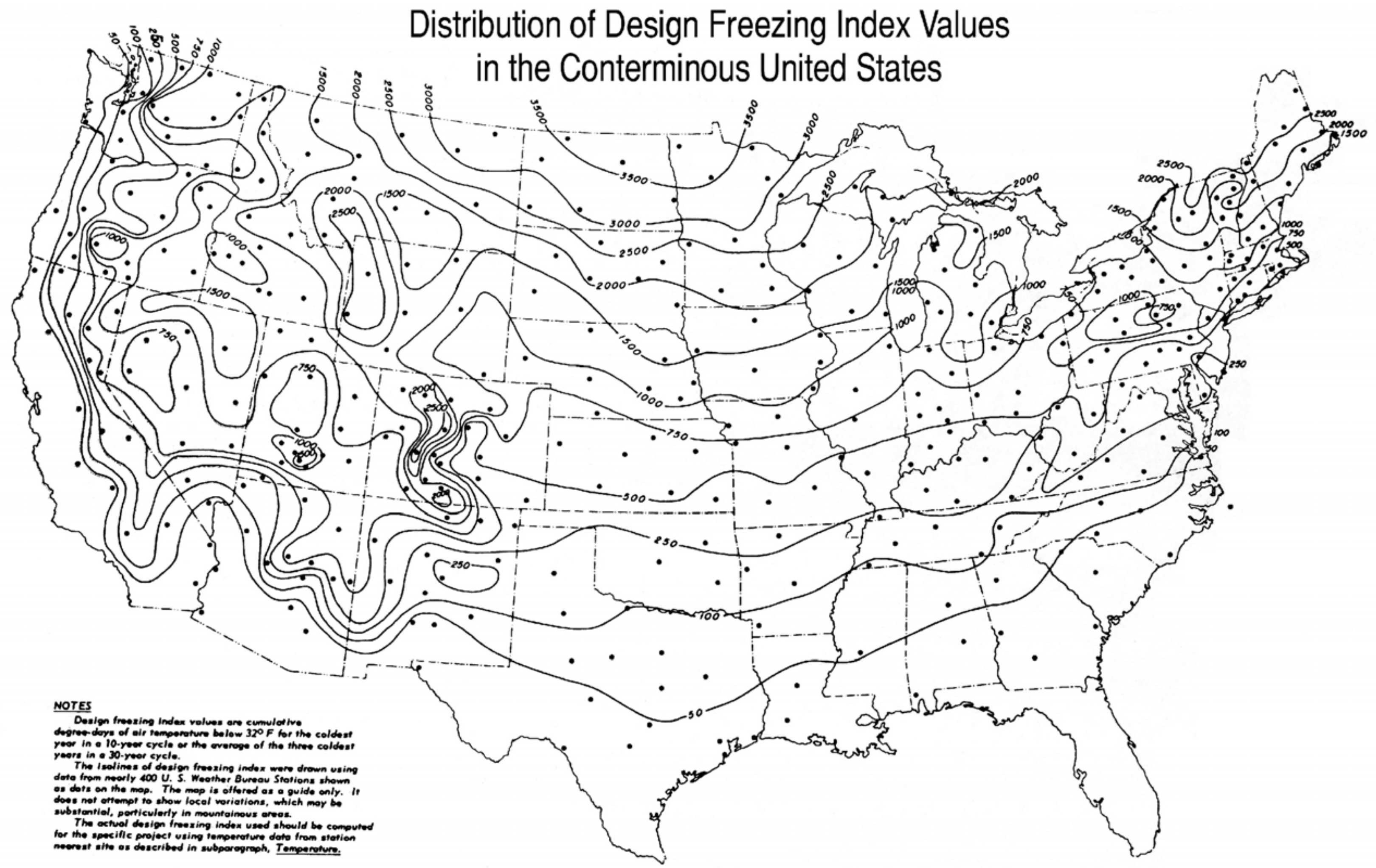
Soil moisture regime	**Frost action classes** [1]		
	Low	**Moderate**	**High**
Aquic	Cindery Fragmental Pumiceous	Sandy Sandy-skeletal	Coarse-loamy Fine-loamy Coarse-silty Fine-silty Loamy-skeletal Clayey and clayey skeletal Organic soil materials Ashy, ashy-pumiceous, and ashy-skeletal Medial, medial-pumiceous, and medial-skeletal Hydrous-pumiceous Hydrous-skeletal Hydrous

Table 3-9. Potential Frost Action (Exhibit 618-5 from USDA 2003)

Soil moisture regime	Frost action classes [1]		
	Low	**Moderate**	**High**
Udic, Xeric, Ustic (when irrigated) Aridic (when irrigated)	Fragmental Cindery Sandy Sandy-skeletal Pumiceous	Coarse-loamy Fine-loamy Loamy-skeletal Clayey Clayey-skeletal Ashy-pumiceous Ashy-skeletal Hydrous-skeletal Medial-skeletal Medial-pumiceous	Coarse-silty Fine-silty Ashy Medial Hydrous-pumiceous Hydrous
Ustic, Aridic	Fragmental Sandy Sandy-skeletal Clayey Clayey-skeletal Cindery Ashy, ashy-pumiceous, & ashy-skeletal Medial and medial-skeletal Pumiceous	Coarse-loamy Fine-loamy Coarse-silty Fine-silty Loamy-skeletal Medial-pumiceous Hydrous-pumiceous Hydrous-skeletal Hydrous	

[1] Family texture classes apply to the whole soil to the depth of frost penetration.

Figure 3-10. Distribution of Design Freezing Index Values in the Continental US (Exhibit 618-6 from USDA 2003)



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3.3 Failure Analysis and Risks of Biota Transfer

From a numbers perspective, the preliminary failure analysis for the engineering system captured in the conceptual designs characterized in DEIS (Reclamation 2005a) may be simplified as a 3-step process to move water from Missouri River basin to the Red River basin. As a first approximation of system failure, an engineer or a reliability analyst would characterize this 3-step process by a "bathtub curve" (Figure 3-11). Mathematically, the engineer's bath tub curve characterizes a "life-time" distribution of failures similar to life tables common to biological and ecological processes (see, e.g., Fleming and Harrington 1991, Meeker and Escobar 1998, Hosmer and Lemeshow 1999, Caswell 2001, O'Connor 2002, Lee and Wang 2003, Lee 1992, Smith 2002, Rausand and Høyland 2004, Reliasoft 2005a,b).

3.3.1 The "Bathtub curve." Section 2 and Appendix 1 include a more detailed discussion of the bathtub curve within the context of this preliminary failure analysis. A plot of the failure rate over time yields a curve that vaguely resembles a longitudinal section of a bathtub (Figure 3-11). If sample size is sufficient and failures are observed in the population through time, estimates of the failure rate λ or $h(t)$ (depending on nomenclature; see Section 2).

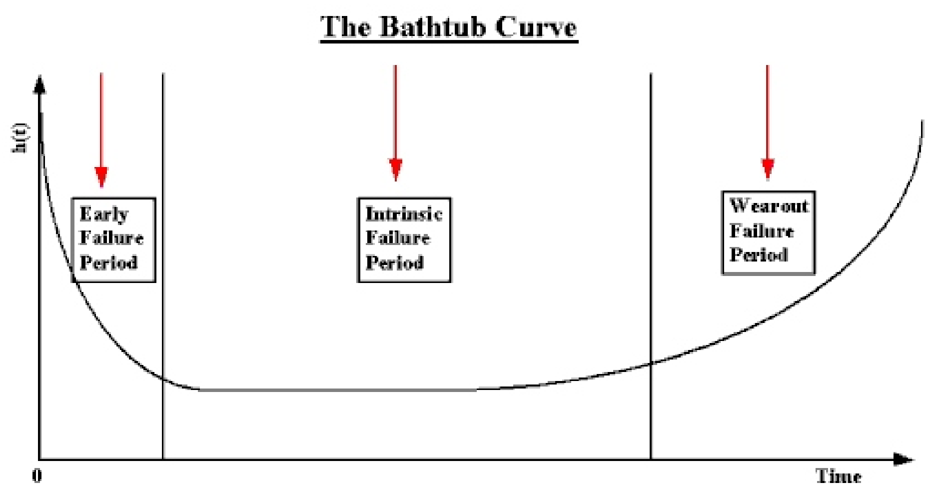


Figure 3-11. Typical "bathtub" curve of the reliability engineer (modified from original NIST source material).

As illustrated in the idealized bathtub curve in Figure 3-11, life time begins at time zero (t_0) when a system's operation commences (which is analogous to birth and early life within the context of a life table). The system is initially characterized by a relatively high, but rapidly decreasing failure rate; the decreasing failure rate typically lasting several weeks to a few months depending on the system. Following the initial, frequently transitory high failure rates characteristic manifest in the “early failure period,” failure rate levels off and remains relatively constant throughout “useful life of the system” which may be characterized by an “intrinsic failure rate.” In sustainable systems, intrinsic failure rates will be low, but systems presenting zero failures are few, if any. Useful life of the system is generally a long period relative to system life time, and is frequently referred to as the intrinsic failure period or the stable failure period. Systems generally function most of their lifetimes in this flat portion of the bathtub curve, but if observations are unbound, the system is not repairable and remains in use long enough, failure rates will increase as materials wear out and degradation failures occur at an ever increasing rate. This “wearout failure period” may follow any number of time courses and will vary from system to system.

Based on empirical observation, the bathtub curve also applies to repairable systems. In repairable systems, a “repair rate” or the “rate of occurrence of failures” (ROCOF) would characterize the ordinate of Figure 3-11 rather than a simple failure rate. This repairable-system approach may be indicated, once Action Alternatives are winnowed to a select number that are more fully developed with respect to engineering specification, but this preliminary analysis opted for a treatment closer aligned with that used to evaluate non-repairable systems. A different approach should be used for modeling the repair rates for a repairable system, once specified. For example, in repairable systems, failures occur at given system ages and once a system is repaired, its status may be as good as new. Alternatively, the system may be better than or worse than the original system. Frequency of repairs may increase, decrease, or remain relatively constant and is generally characteristic of a given system.

Action Alternatives and Lifetime distribution models. As summarized in Section 2 and Appendix 1, lifetime distribution models are commonly applied to investigations such as that completed for this preliminary failure analysis. The preliminary analysis that follows relies on exponential and Weibull models to estimate failure probabilities for Action Alternatives presented in DEIS (Reclamation 2005a). While subsequent engineering analysis will undoubtedly provide higher resolution, each of the Action Alternatives presently envisioned by Reclamation (2005a) for meeting the water demands of Red River valley amounts to pumps and motors, valves with motors, pipe of varying diameters, and other components connected as a network of varying complexity, depending on the alternative. The system may be simplified in this analysis as independent modules that consists of intake, treatment, and transmission functions. Some alternatives, e.g., that rely directly on the Missouri River for source waters via a horizontal well, have incorporated applications other than those traditionally employed for tapping into source, applications which may yield additional risk reduction measures not available in options that tap surface water close-to-grade using wet-sump pumps. Components within these water withdrawal and transmission systems include biota treatment, largely of two types, all of which are hooked up in series. As depicted in the conceptual designs, each Action Alternative largely exists as a system in series; hence, regardless the Action Alternative configuration, for this preliminary analysis the pipes within the water transmission system are considered as occurring in series rather than parallel. When fully designed, the system will undoubtedly have redundancies (e.g., backup generators to power motors on pumps, pumps in series with various numbers of pumps engaged to meet demand), but because of, e.g., project costs, it is anticipated that very little of the system will be built in parallel.

Given this setting, this preliminary failure analysis focused on Action Alternatives linked to an interbasin water transfer. In characterizing risks associated with potential failures, system attributes shared by Action Alternatives are noted. Three systems rely on source water taps at McClusky Canal, and one system relies on network of horizontal wells tapping alluvial sources directly on the Missouri. All four systems rely on coagulation-flocculation-sedimentation and UV disinfection as a conventional treatment regimen integrated into the biota treatment module of the system; a single alternative has a lime softening and microfiltration process involved as part of the biota treatment process. Each interbasin-water-diversion alternative relies on a transmission pipeline whose length critically affects risk. System configuration complicates a simple reliance on length of pipeline as a key element in reducing risks of system failure, e.g., shortest length pipeline does not infer lowest risk, and the longest pipeline serving to transfer treated water presents risks unique to its design (see Section 7).

Output illustrated in Figure 3-12 is based on Weibull analysis that yields an illustrative life-time distribution for a generalized water treatment and transmission envisioned in the conceptual designs considered in the DEIS (Reclamation 2005a). While future iterations will benefit from full designs, the preliminary analysis focused on a simple implementation equally amenable to characterization of failures in any of the Action Alternatives to encourage discussion currently ongoing. Parameterization of this preliminary Weibull analysis is summarized in Table 3-10 for the 10,000-day period that captures an early failure period, a period of useful life (characterized by constant failure rate), and late life (characterized by variably increasing failure

Table 3-10. Summary of Weibull parameterization and a brief summary of the Weibull function and its calculation in the current investigation.

Time in Days	Values of Weibull parameters*			Comment**
	Alpha	*Beta*	*Gamma*	
1 through 30	1	10	0	Early operations failures (linked, e.g., to manufacturing defects of components)
31 through 60	1	25	0	As early operations identify problem components, system reliability increases
61 through 90	1	50	0	Increasingly reliable system
91 through 360	1	200	0	System "burn in" complete and enters period of "constant failure rate"
361 through 7500	1	500	0	System performs with 30-day moving average failure rate ranging between 1E-5 and 1E-6
7501 through 7600	2	3	0	System enters period of age-related increased numbers of failures (infrequent)
7601 through 8000	2	2.5	0	System characterized by increased numbers of failures (infrequent to common)
8001 through 9000	1.5	3	0	System characterized by increased numbers of failures (common)
9001 through 10,000	1	7	0	System characterized by increased numbers of failures (increasingly frequent)

*preliminary output summarized in Figure 3-12 generated through MS Excel VBA add-in. Color code for narrative risks associated with each phase of lifetime distribution: red, risks considered to change from very high to high to moderate levels within period; green, risk maintained at moderate to low levels within period; yellow, risk considered to be increasing to mirror age-related failures being experienced.

**Weibull distribution. The negative exponential and normal distributions are often close approximations to real failure patterns. Often, however, these two distributions present an oversimplification of reality. For this reason the Weibull Distribution was originally developed (Abernethy 2000, Murthy, et al. 2004). This preliminary Weibull analysis opts for a generalized empirical distribution, which can represent any failure pattern, particularly when full design details are available. The Weibull distribution represents a great variety of actual failure distributions, with the probability density function given by:

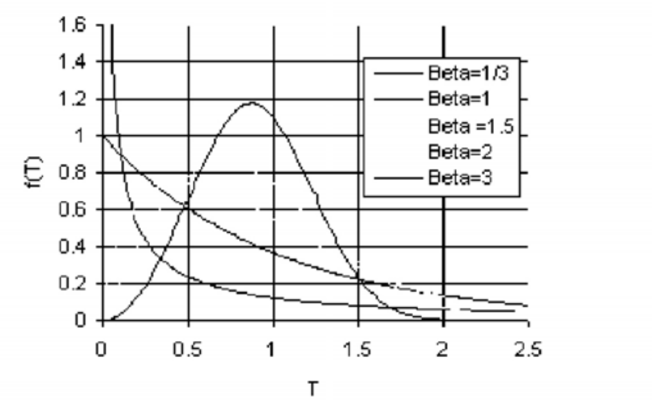
$$f(T) = \frac{\beta (T-\gamma)^{\beta-1}}{\alpha^{\beta}} e^{-\left(\frac{T-\gamma}{\alpha}\right)^{\beta}}$$

where

β = Shape parameter
γ = Location parameter
α = Scale parameter, also known as the characteristic life, and
T = Time

Failure probability density function, f(T), is a curve under which the area is unity (100%, probability = 1.0). The percentage of items that will have failed by some intermediate value T is the area under the curve from T = 0 to T = T.

The following figure puts the above equation into context. It compares the Weibull probability density function (f(T)) for various values of β when α = 1 and γ = 0.



The curve demonstrates what happens for the various values of β:

$\beta < 1$, a hyperexponential case where there is decreasing failure rate with T, a condition generally characteristic of the "infant mortality" or early failure stage of a product life. Alternatively, the hyperexponential may reflect bad installation of the component or defect in product associated with quality assurance practices in manufacture.

$\beta = 1$, a negative exponential case where the failure rate is constant, thus the components will fail randomly.

$1 < \beta < 2$, a skewed distribution that indicates an increasing failure rate with time.

$\beta \geq 2$, with approximates a normal distribution. Represents wear out failures.

As forecast in the figure, it is often possible to discard the γ parameter, implying that all functions begin at T = 0, which is a very common case. The characteristic life α represents the value of T where 63.2% of the population can be expected to have failed or had a defect.

In Visual Basic Application (VBA), the command WEIBULL returns the Weibull distribution.

Syntax

WEIBULL(**x**,**alpha**,**beta**,**cumulative**)
x is the value at which to evaluate the function.
Alpha is a parameter to the distribution.
Beta is a parameter to the distribution.
Cumulative determines the form of the function.
Remarks

If x, alpha, or beta is nonnumeric, WEIBULL returns the #VALUE! error value.
If x < 0, WEIBULL returns the #NUM! error value.
If alpha ≤ 0 or if beta ≤ 0, WEIBULL returns the #NUM! error value.

The equation for the Weibull cumulative distribution function is:

[redacted]

The equation for the Weibull probability density function is:

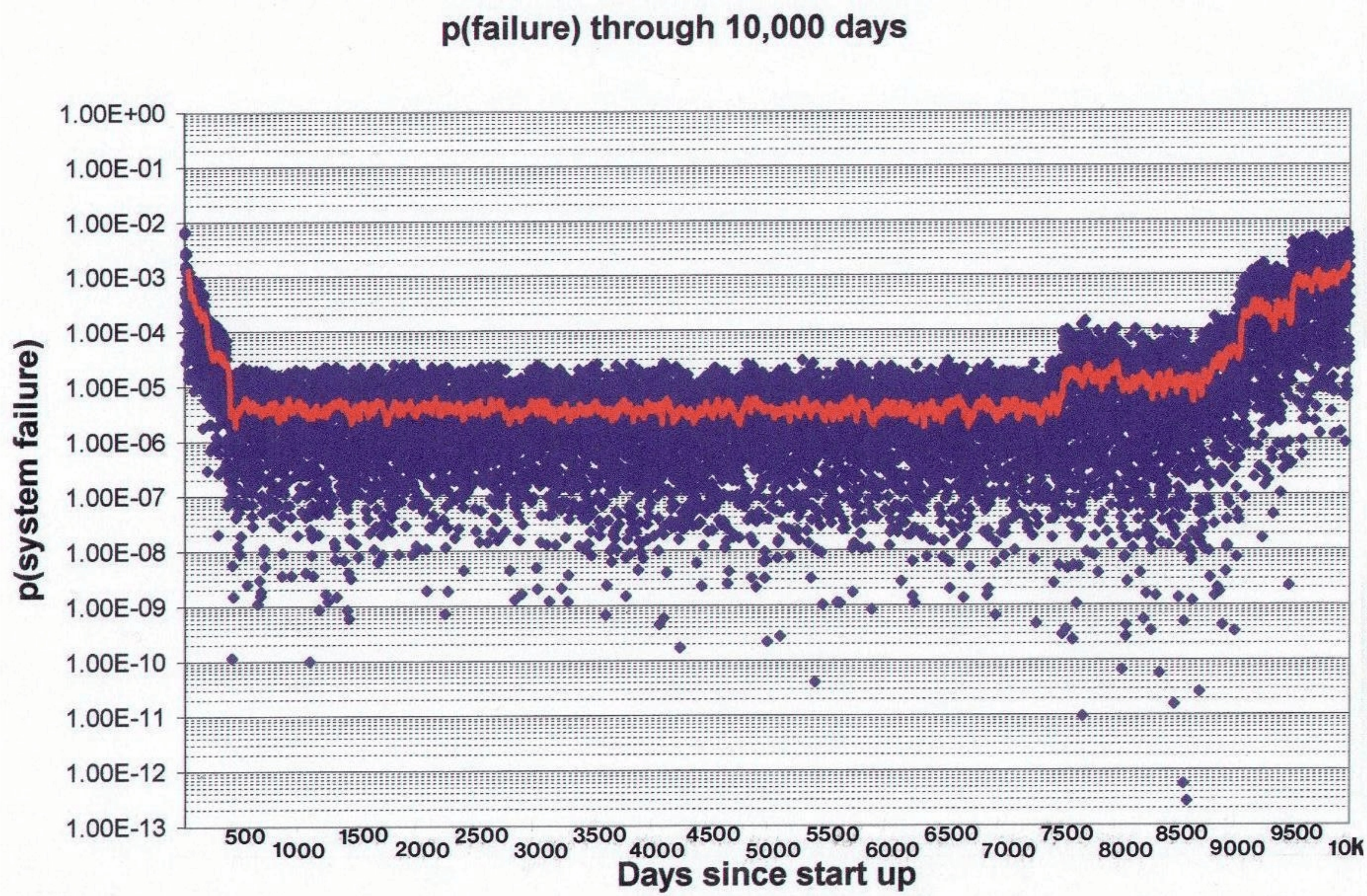
[redacted]

When alpha = 1, WEIBULL returns the exponential distribution with:

[redacted]

The reader is referred to Appendix 1 and Section 8 for additional detail on Weibull analysis and its role in failure analysis.

Figure 3-12. 30-day moving average for p(system failure).


p(failure) through 10,000 days
p(system failure)
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10K
Days since start up

rate). Intake throughout the 10,000-day project is conservatively considered as random input without distinction being given to differences between source waters derived from horizontal wells[14] or wet-slurry pump operations. This assumption stems from observation that controlling source water quality may be impractical given the, e.g., seasonal variability and watershed characteristics of the Missouri River upstream from points of intake. Failures during this "start up" period are conservatively assumed to positively effect biota transfer; that is, all failures were assumed to enhance biota releases. Recall, water withdrawal, water treatment, and conveyance functions of the water-transfer control system could also realize reduce risks of biota release, if those failures resulted in an interruption of water transfer, e.g., pump failure may ceased water transfer. However, recognizing the potential failures associated with system re-start, e.g., pressure-related malfunctions in water treatment module or conveyance module, this conservative assumption is not unjustified in a preliminary analysis. Overall, the assumption that any failure would yield biota transfer was consistent with the conservative context expressed by Reclamation and stakeholders, which may be characterized as one failure is sufficient to realize biota transfer via interbasin water diversion as reflected in USGS (2005a). During the period of useful life, constant failure is considered as a random variable bounded by a Bin 1 value for LT2ESWR as an upper limit of performance, and during late life increasing failure rates are initially considered as outcomes associated with failures associated with aging pipe in the transmission system.

In part, the outcome of the simple scenario considered in this preliminary analysis is supported by existing data and information. A focused survey on failure rates for various transmission system components as tallied by various government and industry sources provide alternatives that could be incorporated into stakeholder applications of this simple bathtub life time distribution or alternatives of their choosing (see Section 2). Sufficient to a preliminary failure analysis, empirical failure rates are assembled in Table 3-11a,b,c (DIP, ST pipe, and PVC pipe, respectively; see also Figure 3-13) and Table 3-12 (pumps and valves; see also Figure 3-14 and Figure 3-15) and provide an initial characterization of failures associated with components potentially identified for the built system. Figure 3-15 presents box plots to characterize failure rates for control-system component across large composite groupings, e.g., pumps and values.

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[14]This assumption may undervalue the role of radial collector well technologies in "pre-treating" source waters, e.g., intake through alluvial materials underlying the water source may yield water quality similar to that attained as output of sand filtration.

The useful life, or intrinsic failure period, captured in the simple scenario's life time bathtub curve in Figure 3-12 was developed under the guiding principle that no system is free of failure; that is, even the "best systems" fail. Following the start-up period, the intrinsic failure period may likely be linked to a system designed to meet performance criteria consistent with LT2ESWTR (e.g., Bin 1 value in filtered systems as < 0.075 *Cryptosporidum* oöcysts/L), yet fails. While LT2ESWTR bin designations vary depending on the system being considered under the rule, these public health-related values may be applicable to broader environmental applications, given the benchmark organism is targeted on physical dimension that may be applicable to other biota potentially co-occur in the source waters (e.g., *Mxyobolus cerebralis* spores are typically 7.5µm to 8.75µm at either major or minor axis, see Appendix 4, USGS [2005a] or see Hogge, et al. 2004 among others; *C. parvum* spores variously range between 2µm to 4µm, see Appendix 4, USGS [2005a] and references cited therein; see also, Mamane-Gravetz and Linden 2005 and http://www.env.gov.bc.ca/wat/wq/reference/protozoans.html#tofc among others). These surrogate values applied in this preliminary analysis suggest that risks of, e.g., infectious agents the size of *Cryptosporidium parva* may be transferred in a biota treatment plant characterized by the best available membrane technology.

Through the intrinsic failure period—considered here between Day 361 through Day 7500—the system would fail to meet performance criteria through potentially one or more failure modes, e.g., "short circuiting" effects limit membrane filtration from achieving a goal of zero risk (Schippers et al. 2004) or undetected leaks allow water loss to cumulatively release sufficient propagules to the environment to achieve biota transfer. System performance illustrated in Figure 3-12 considers nominal operations within regulatory specifications consistent with LT2SWTR during useful life, wherein system functions as a best engineering practice to achieve reduction for *C. parvum* and constituents having physical dimension equal to or greater than *C. parvum* (see Appendix 10, USGS [2005a]). In Figure 3-12, failure rate is simply considered time invariant and linear, varying and bound by 10^{-3} but greater than 0. The inflection between the early failure period and the period characterized by an intrinsic failure rate is illustrated in Figure 3-12 by a relatively abrupt transition within the life time distribution, which on repeated iterations of the analysis (e.g., using empirically-based resampling efforts) would likely be diminished. In the current analysis, a 30-day moving average of failure rate captures the trends in failure throughout the 10,000-day illustrative forecast. A cursory comparison of daily outcomes relative to trends estimated by a 30-day moving average suggest potential risks may be muted by the latter forecasts, if a single breach in system performance, e.g., a spore or oöcyte from *C. parvum* or similarly sized agent, is sufficient to initiate successful species invasions or shifts in metapopulations.

Age-related failures become dominate factors in evaluating system performance through time. While the single projection illustrated in Figure 3-12 may be reiterated opting for alternative input valves, e.g., derived from the available empirical failure data, daily outcomes and 30-day moving average trends observed in this analysis follow a typical Weibull function where scale, shape, and location parameters (see Section 2.0) are arbitrarily input (Table 3-10), effectively increasing the slope—hence, increasing failure rate—for trends in the system through the balance of the 10,000-day projection. As will be noted in Section 7, the uncertainties associated with this preliminary analysis are commensurate with the specifications of the conceptual design. As full design for water treatment and water transmission system becomes available, multiple scenarios of varying complexities—simple linear networks of serially arranged components to highly interconnected networks presenting parallel structures—may be considered in a complete engineering analysis.

Preliminary estimates of system failures and analysis of risks of biota transfer. The uncertainties associated with the simple scenario identified here will be considered in Section 7, but elaboration beyond the 3-module—intake, treatment, conveyance—system briefly here is better left to more fully developed engineering designs identified as outcomes of the NEPA process, including, e.g., regulatory specification of limiting values or performance criteria necessary for full design. Various outcomes from a fully integrated engineering failure and reliability analysis, once alternative of choice is identified, would better serve stakeholder concerns than an endless series of preliminary analyses challenged by consistent under specification. Hence, in this preliminary failure analysis of Action Alternatives, coarse estimates may help focus on those components of the selected system's life time that are most critical in regard to risk of biota releases that might result from infrastructure failure. Preliminary estimates of failure probability for the system are developed to set the stage for linking failures to vulnerable habitats characterized in Section 4 and evaluated in Section 5 and Section 6. A characterization of risks and their attendant uncertainties follows in Section 7.

Given the conceptual designs for Action Alternatives developed in the DEIS (Reclamation 2005a), the simple scenario illustrated in Figure 3-12 was considered in categorical risk estimates for system failure:

- Risk of system failure in “early life” (initial year of operation) would be considered moderate to high, and is conservatively estimated at 1 out of 10,000 for system failure yielding a biota transfer,
- Risk of system failure during “useful life”(bounded between 1-year and up to 20-years service life) would be considered low to moderate, and is conservatively estimated at 1 out of 100,000 for system failure yielding a biota transfer, and
- Risk of system failure during “late life” (beyond 20 years service life) would be considered high to very high, and is conservatively estimated at 1 out of 1000

Bear in mind, regardless of when system failure occurs, these conservative estimates assume that a single system failure will yield a successful biota transfer, and a sustainable population will be established consequent to that system breach. As noted in USGS (2005a), this fail-once assumption may be possible, but not highly likely, and depends on the spatiotemporal attributes that characterize when and where the failure occurs. While multiple scenarios should be considered in an engineering failure analysis, these conservative estimates have been developed in order to link these preliminary estimates of failure to HEA as a measure of consequences. These categorical estimates serve as bins for numerical outputs illustrated in Figure 3-12 and range widely between bounds based on empirical data, wherein available failure rates for components such as pumps, valves, gates, and pipes were assumed as representative of larger macro-rate failure probabilities for the system.

Table 3-11a. Existing failure data for DIP.

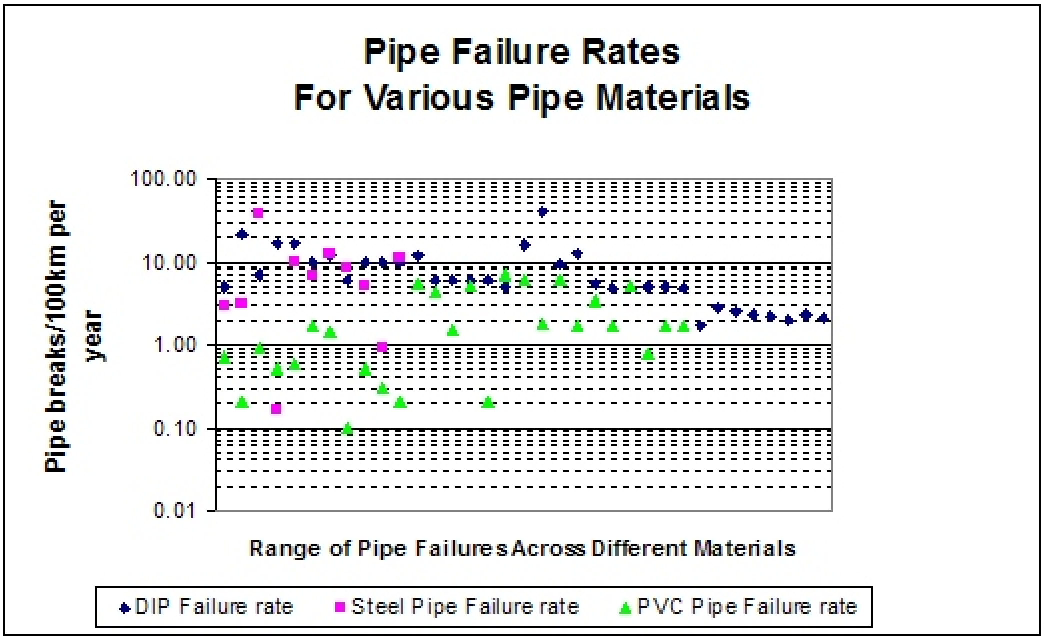
Ductile Iron Pipe Failure rate (breaks per 100 km per year)	Reference
5.0	Threshold value (Norway)
21.0	Threshold value (Belgium)
7.0	Threshold value (Denver)
17.0	Threshold value (Oakland)
17.0	Threshold value (US average)
10.0	Lusiba (2003)
12.0	Lusiba (2003)
6.0	Lusiba (2003)
10.0	Lusiba (2003)
10.0	Lusiba (2003)
10.0	Lusiba (2003)
12.0	Lusiba (2003)
6.0	Lusiba (2003)
6.0	Lusiba (2003)
6.0	Lusiba (2003)
6.0	Lusiba (2003)
5.0	Lusiba (2003)
15.5	Lusiba (2003)
40.0	Lusiba (2003)
9.5	Rajani and MacDonald (1995)
12.4	AWWA Water Loss Control Committee (2003)
5.4	Kleiner & Rajani (2002)
4.8	Kleiner & Rajani (2002)
4.8	Kleiner & Rajani (2002)
4.9	Kleiner & Rajani (2002)
4.9	Kleiner & Rajani (2002)
4.7	Kleiner & Rajani (2002)
1.7	Deb, et al. (1995)
2.8	Deb, et al. (1995)
2.5	Deb, et al. (1995)
2.3	Deb, et al. (1995)
2.2	Deb, et al. (1995)
2.0	Deb, et al. (1995)
2.3	Deb, et al. (1995)
2.1	Deb, et al. (1995)
2.2	**10th percentile**
6.0	**median**
16.4	**90th percentile**

Table 3-11b. Existing failure data for ST pipe.

Steel Pipe Failure rate (breaks per 100 km per year)	Reference
2.94	Fleming and Lydell (2004)
3.03	Fleming and Lydell (2004)
38.46	Fleming and Lydell (2004)
0.17	Fleming and Lydell (2004)
10.00	Energy Institute, London (2003)
6.67	Energy Institute, London (2003)
12.50	Energy Institute, London (2003)
8.33	Energy Institute, London (2003)
5.26	Energy Institute, London (2003)
0.91	Energy Institute, London (2003)
11.11	Energy Institute, London (2003)
0.318	**10th percentile**
6.670	**median**
33.260	**90th percentile**

Table 3-11c. Existing failure data for PVC pipe.

PVC pipe Failure rate (breaks per 100 km per year)	Reference
0.7	Rajani and MacDonald (1995) as cited by Unibell (UNI-PUB-10-04)
0.2	Brander (2004) as cited by Unibell (UNI-PUB-10-04)
0.9	NRC Canada (1995)
0.5	NRC Canada (1995)
0.6	Burn et al. (2005)
1.7	Burn et al. (2005)
1.4	Burn et al. (2005)
0.1	Burn et al. (2005)
0.5	Burn et al. (2005)
0.3	Burn et al. (2005)
0.2	Burn et al. (2005)
5.4	Burn et al. (2005)
4.3	Burn et al. (2005)
1.5	Burn et al. (2005)
5.3	Burn et al. (2005)
0.2	Burn et al. (2005)
6.8	Burn et al. (2005)
6.1	Burn et al. (2005)
1.8	Burn et al. (2005)
6.0	Burn et al. (2005)
1.7	Burn et al. (2005)
3.4	Burn et al. (2005)
1.7	Burn et al. (2005)
5.1	Burn et al. (2005)
0.8	Burn et al. (2005)
1.7	Burn et al. (2005)
1.7	Burn et al. (2005)
0.2	**10th percentile**
1.7	**median**
5.6	**90th percentile**



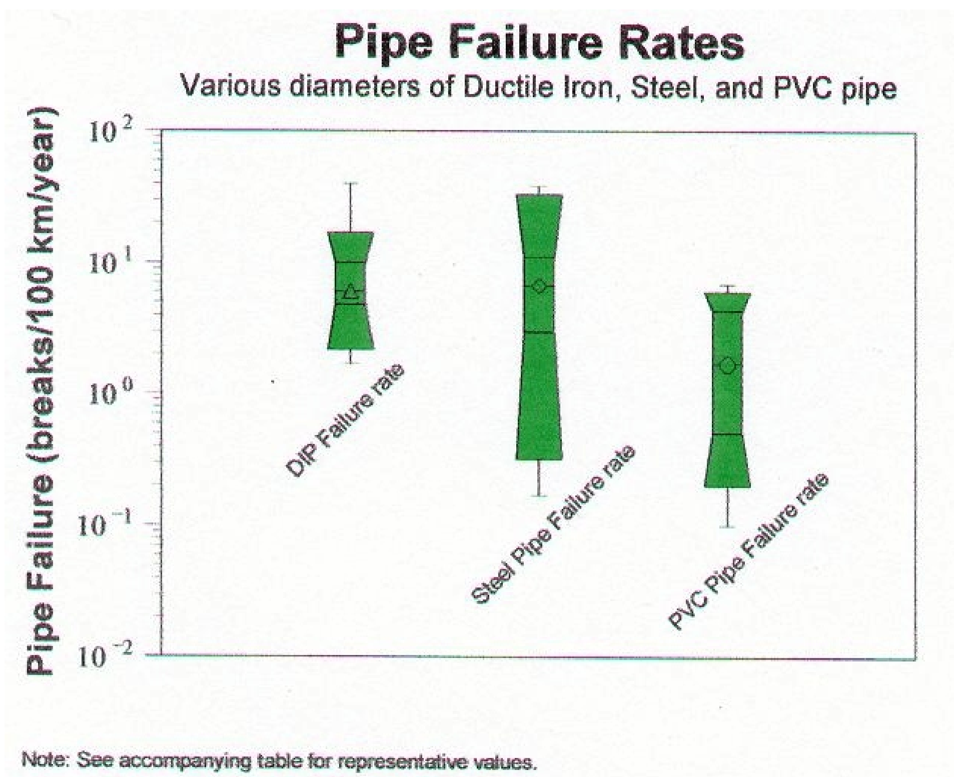


Figure 3-13. Scatter plot (top) of pipe failure rates across material types, and box plots (bottom) summarizing distributions of failures for each material (DIP, ST pipe, PVC pipe).

Table 3-12. Existing failure data representative of pumps and valves potentially incorporated into system engineering designs.

Failure mode	Machinery, Pumps (All kinds)[1]	Number of failures	Failure rate (per 10E6 hours)				Comment
			Lower	Mean	Upper	Std. Dev.	
Critical		524	0.00	20.52	108.44	49.34	
Degraded		754	0.00	44.20	210.34	86.32	
Incipient		1124	0.08	55.97	228.31	86.32	
Unknown		21	0.00	2.04	9.97	4.16	
	Machinery, Pumps (centrifugal water lift pumps)[1]	**Number of failures**	**Failure rate (per 10E6 hours)**				**Comment**
			Lower	**Mean**	**Upper**	**Std. Dev.**	
Critical		39	16.33	47.12	90.83	23.31	
Degraded		45	5.97	64.47	176.93	57.19	
Incipient		55	5.40	71.30	202.78	66.56	
Unknown		1	0.00	1.08	5.53	2.40	
	Machinery, Pumps (centrifugal water system pumps)[1]	**Number of failures**	**Failure rate (per 10E6 hours)**				**Comment**
			Lower	**Mean**	**Upper**	**Std. Dev.**	
Critical		11	0.00	1.70	6.67	2.48	
Degraded		35	0.00	8.77	45.70	20.38	
Incipient		87	0.00	32.35	177.30	83.00	
Unknown		none reported					
	Machinery, Pumps (centrifugal water injection pumps)[1]	**Number of failures**	**Failure rate (per 10E6 hours)**				**Comment**
			Lower	**Mean**	**Upper**	**Std. Dev.**	
Critical		147	0.80	122.12	423.59	156.24	
Degraded		144	4.86	120.63	363.17	123.09	
Incipient		367	84.43	298.43	619.31	169.05	
Unknown		1	0.00	0.94	4.35	1.76	
			Lower	**Mean**	**Upper**	**Std. Dev.**	
All modes		2423	0.12	123.75	515.05	196.22	
			Lower	**Mean**	**Upper**	**Std. Dev.**	
All modes			0.67		6.67		

	Machinery, Pumps[3]	**Number of failures**	**Failure rate (per 10E6 hours)**				**Comment**
			Lower	**Mean**	**Upper**	**Std. Dev.**	
All modes	Centrifugal, Axial flow impeller and Peripheral		3.30		10.00		Upper and lower values on range of failure rates originally characterized as MTBF.
	Mixed flow and radial flow impeller		3.30		10.00		Upper and lower values on range of failure rates originally characterized as MTBF.
	Machinery, Pumps[4]	**Number of failures**	**Failure rate (per 10E6 hours)**				**Comment**
			Lower	**Mean**	**Upper**	**Std. Dev.**	
All modes			29.66	44.49	53.62		
	Machinery, Pumps[5]	**Number of failures**	**Failure rate (per 10E6 hours)**				
			Lower	**Mean**	**Upper**	**Std. Dev.**	
All modes	Centrifugal, open impeller			45.500			Derived from value for MTFB
	Axial flow, propeller			13.500			Derived from value for MTFB
	Machinery, Pumps[5]	**Number of failures**	**Failure rate (per 10E6 hours)**				**Comment**
			Lower	**Mean**	**Upper**	**Std. Dev.**	
All modes	Pump, centrifugal			45.500			Derived from value for MTFB
				2.200			Derived from value for MTFB
				7.100			Derived from value for MTFB
			Lower	**Mean**	**Upper**	**Std. Dev.**	
	Pump, axial flow			13.500			Derived from value for MTFB

	Machinery, Pumps[4]	**Number of failures**	**Failure rate (per 10E6 hours)**				**Comment**
			Lower	**Mean**	**Upper**	**Std. Dev.**	
All modes	Centrifugal		125	130	134		Upper and lower values valued at 80% confidence bounds
	Centrifugal, Horizontal		139	145	150		Upper and lower values valued at 80% confidence bounds
	Centrifugal, Vertical		94	110	128		Upper and lower values valued at 80% confidence bounds
	All pumps		124	127	130		Upper and lower values valued at 80% confidence bounds

1Source: OREDA (2002)

2Source: Bloch and Geitner (1999)

3Source: Handbook of reliability prediction procedures for mechanical equipment

4Source: Barringer and Moore (1999)

5Source: Shultz and Parr (1981) as cited in Mays and Cullinane (1986)

Note: 10E6 hours is approximately 114 years

Failure mode	Valves (All kinds)	Number of failures	Failure rate (per 10E6 hours)				Source data: OREDA (2002) unless noted
			Lower	Mean	Upper	Std. Dev.	
Critical		358	0.01	6.79	28.28	10.78	
Degraded		302	1.08	8.47	21.73	6.77	
Incipient		339	3.53	14.93	32.80	9.32	
Unknown		18	0.00	0.35	1.80	1.47	
	Valves (Ball valve)	**Number of failures**	**Failure rate (per 10E6 hours)**				
			Lower	Mean	Upper	Std. Dev.	
All modes	Water injection line		0.05	11.75	45.12	16.62	
	Valves (Butterfly valve)	**Number of failures**	**Failure rate (per 10E6 hours)**				
			Lower	Mean	Upper	Std. Dev.	
All modes	Within cooling line	2	1.93	10.87	34.22	10.87	
	Valves (Butterfly valve)	**Number of failures**	**Failure rate (per 10E6 hours)**				
			Lower	Mean	Upper	Std. Dev.	
All modes	Within water lift system	2	6.75	38.05	119.77	38.05	
All modes	Within water injection system	6	49.75	114.16	225.27	114.16	
All modes	Within water service system	3	15.60	57.08	147.55	57.08	
	Valves [Shultz and Parr (1981) as cited in Mays and Cullinane (1986)]	**Number of failures**	**Failure rate (per 10E6 hours)**				
			Lower	Mean	Upper	Std. Dev.	
All modes	Gate valve	NA		125.000			Derived from value for MTFB
	Ball valve	NA		90.900			Derived from value for MTFB
	Butterfly	NA		30.300			Derived from value for MTFB
	6-12 inch	NA		18.200			Derived from value for MTFB
	13-24 inch	NA		90.900			Derived from value for MTFB
	25-48 inch	NA		52.600			Derived from value for MTFB
	> 48 inch	NA		125.000			Derived from value for MTFB

	Valves [Shultz and Parr (1981) as cited in Mays and Cullinane (1986)]	Number of failures	Failure rate (per 10E6 hours)				
			Lower	Mean	Upper	Std. Dev.	
All modes	Ball valve	NA		90.900			Derived from value for MTFB
		NA		12.500			Derived from value for MTFB
	Butterfly	NA		31.250			Derived from value for MTFB
		NA		2.000			Derived from value for MTFB
		NA		1.360			Derived from value for MTFB
	Gate	NA		111.100			Derived from value for MTFB
		NA		5.100			Derived from value for MTFB
		NA		1.440			Derived from value for MTFB

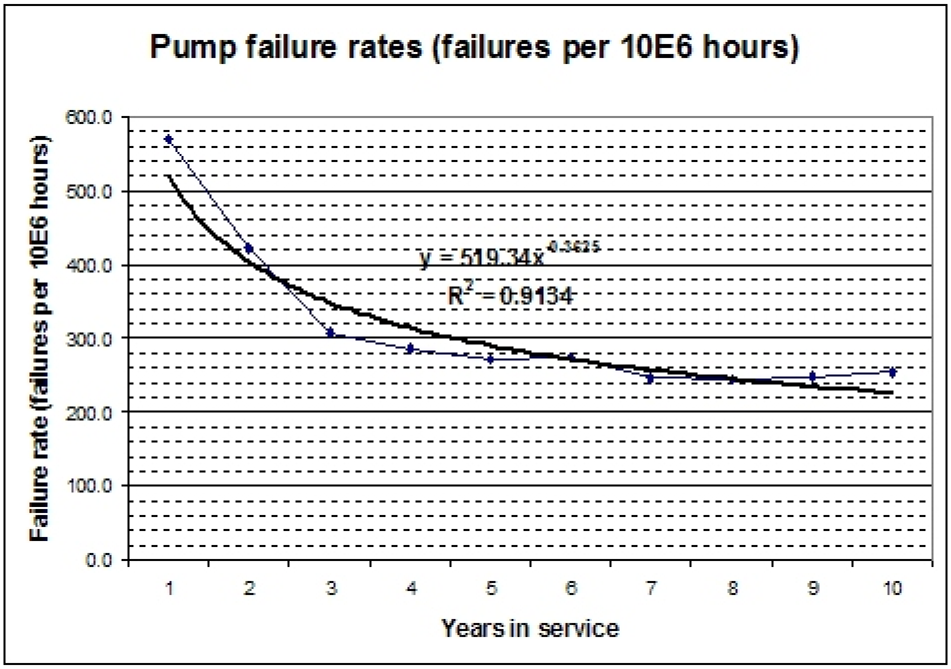
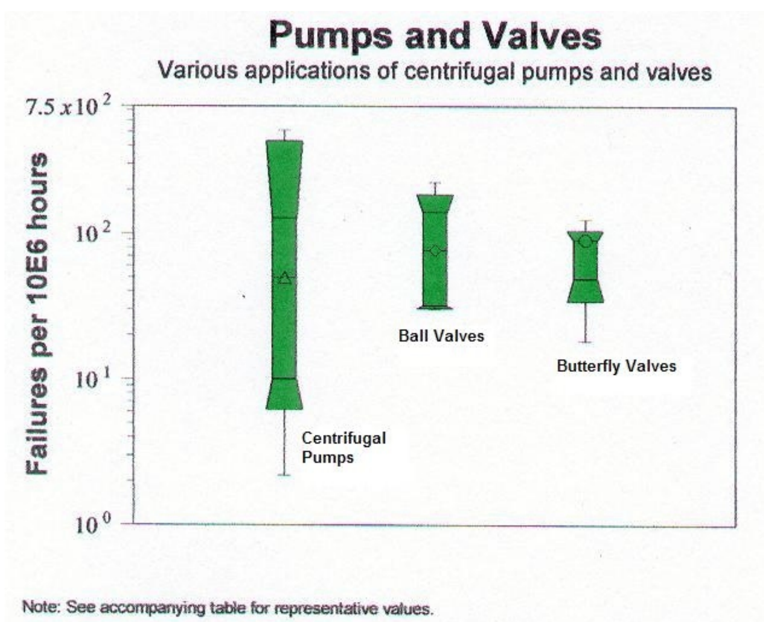


Figure 3-14. Simple exponential failure function developed for pump failures potentially serving as modular failure data during early failure period in a typical bathtub life time distribution.
Figure 3-15. Box plots illustrating the distributions of failure rates for centrifugal pumps and



valves potentially occurring as components within control systems developed in fully designed Action Alternatives.

4.0 Ecological Characterization of Area of Concern

The DEIS for the Red River Valley Water Supply Project identified eight alternatives that addressed the water needs of the Red River Valley population (Reclamation 2005a). Seven of these alternatives involved the construction of a buried pipeline that would carry water from source areas, and were considered Action Alternatives. The eighth alternative considered was a No Action Alternative, and is the scenario of the future without the Project. Pipeline length for Action Alternatives varied from 35 miles for the main transmission line in the Red River Basin Alternative (not including pipelines from the individual wells and well fields to the main transmission line) to nearly 600 miles (GDU Water Supply Replacement Pipeline Alternative) (Table 4-1; see Reclamation 2005a). The number of North Dakota and Minnesota counties the proposed pipeline routes pass through ranges from 5 to 15 (Table 4-1). The alternatives markedly differ with respect to their location and spatial extent, as well as ecological characteristics (U.S. Fish and Wildlife Service 2005a). Knowledge of the region's ecology can not only inform the routing of the pipeline, but also serves to identify potential environmental impacts both during and after pipeline installation. During installation, a right-of-way will be established or an existing easement will be utilized, and the habitat within that area will be temporarily or permanently altered (Figure 4-1). The width of the right-of-way for the pipeline is presently unknown, but will vary depending on pipe size. A construction easement as wide as approximately 200 feet is expected (Reclamation 2005a). Following installation, pipeline maintenance activities and failures also have the potential to alter right-of-way, nearby habitats, and species dependent on these areas.

In Section 4 we characterize subterranean and surface habitats of the counties through which the proposed pipeline would run, and discuss potential environmental effects in the event of pipeline failure. Failure rates for pipe depend on material of choice, e.g., for large diameter DIP and ST pipe, pipe failures through service life would range between 2.2 to 16.4 (median, 6.0) breaks per 100km per year, and 0.3 to 33.3 (median, 6.7) breaks per 100 km per year, respectively (Section 3). DEIS (2005) and US Fish and Wildlife Service (FWS; 2005a) have indicated that most Project impacts would likely be temporary and relatively small in scale, although the occurrence of water loss along the pipeline route may translate into effects beyond those incurred during and shortly after pipeline installation. Depending on the type of failure within the water treatment and transmission system, effects linked to system failures may be experienced by the surrounding habitats. Some failures, e.g., pump malfunctions leading to system shut down, might also result in transient reductions in risks for pipeline failure, since complete system shutdowns would stop water conveyance in the system. The extent of effects

Table 4-1. Pipeline length and counties crossed by proposed pipeline routes for each Action Alternative [ND, North Dakota; MN, Minnesota]

Action Alternative	Approximate Pipeline Length (miles)	Number of Counties	Counties
GDU Import Pipeline	260	11	ND: Cass, Foster, Grand Forks, Griggs, Richland, Sheridan, Steele, Traill, Wells
			MN: Clay, Polk
GDU Import to Sheyenne River	130	11	ND: Cass, Foster, Grand Forks, Griggs, Richland, Sheridan, Steele, Traill, Wells
			MN: Clay, Polk
GDU Water Supply Replacement Pipeline	600	15	ND: Barnes, Cass, Foster, Grand Forks, Griggs, Ransom, Richland, Sargent, Sheridan, Steele, Traill, Walsh, Wells
			MN: Clay, Polk
Lake of the Woods	260	10	ND: Cass, Grand Forks, Pembina, Richland, Traill, Walsh
			MN: Kittson, Lake of the Woods, Polk, Roseau
Missouri River Import to Red River Valley	300	10	ND: Barnes, Burleigh, Cass, Grand Forks, Kidder, Richland, Stutsman, Traill
			MN: Clay, Polk
North Dakota In-Basin	80	6	ND: Barnes, Grand Forks, Richland, Steele, Traill
			MN: Polk
Red River Basin	35 (main transmission line)	5	ND: Cass, Grand Forks, Richland
			MN: Clay, Polk

Figure 4-1. Habitat alteration resulting from the burial of a water pipeline. Photo credit: Stacy James.

associated with unintended water-release events, e.g., through pipe breaks, would depend on the magnitude, duration, and location of failure event. Also, the time of year during which a failure event occurred would influence expression of effects. Maintenance and repair activities conducted as part of the O&M program would also influence the occurrence of failure events, ideally deferring these in total, or at least minimizing them to insignificant releases. Route selection will be critical to spatially limiting failure-associated effects, ensuring that mitigation of direct effects would be localized.

4.1 Methods

ESRI's ArcGIS Version 9.1 software was used to generate maps of habitat and other environmental features in eastern North Dakota and western Minnesota. These maps encompass all counties crossed by the proposed pipeline routes of the seven Action Alternatives. Resolution is coarse at this scale because of the large geographic area covered; hence, maps were also generated for Griggs County, North Dakota, to provide an example of this loss of resolution and to better demonstrate landscape features potentially of interest to resource managers upon reiteration of pipeline routing in the full design of the system. Griggs County lies just upstream of Lake Ashtabula and is crossed by the proposed GDU Import Pipeline, GDU Import to Sheyenne River, and GDU Water Supply Replacement Pipeline Action Alternatives. GIS data were obtained from a variety of sources, and national-level databases were utilized when possible to minimize reporting differences between the two states (Table 4-2).

Table 4-2. Sources of data layers for GIS maps [USDA = U.S. Department of Agriculture; USGS = U.S. Geological Survey].

Feature	Source
Aquifers	National Atlas of the United States
Chemical Contamination	National Atlas of the United States
Hydrology	National Atlas of the United States
Land Cover	USGS EROS (Earth Resources Observation and Science)
Protected Areas	National Atlas of the United States (federal land)
	North Dakota State Government Metadata Explorer (state land)
	Minnesota Department of Natural Resources Data Deli (state land)
Purple Loosestrife	National Atlas of the United States
Soils	USDA STATSGO (State Soil Geographic database)
Watersheds	National Atlas of the United States
Water Wells	North Dakota State Water Commission
	Minnesota Geographic Data Clearinghouse GeoGateway
Wetlands	USGS EROS (Earth Resources Observation and Science)

Only government-owned protected areas were mapped, but the geographic location of preserves owned by The Nature Conservancy was included in tabular form. Information on water well distribution should be considered conservative and the current operating status of each well is not specified. The well map shows data from private contractor driller logs, but not all wells are reported to state governments and older wells may not be on record. Maps based on driller logs are not fully representative, but are the most complete record of wells. Online, interactive map services provided all soils maps except for permeability (available online from USDA NRCS Web Soil Survey, http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). County distribution information for federally listed species came from US Fish and Wildlife Service publications (2005b, 2006). County occurrence data for state listed species (S1 and S2 rank) were obtained from NatureServe (available at http://www.natureserve.org), which receives regular updates from state Heritage Programs. State listed species data from NatureServe were checked against each state's rare species lists (Minnesota Department of Natural Resources 1996, Dirk 2006a,b).

4.2 Ecological Characterization

The following sections cover the different ecological attributes of the Red River Valley region, and how these attributes may affect or be affected by a water pipeline failure.

4.2.1 Land Cover

The region of eastern North Dakota and western Minnesota is a diverse and heterogeneous landscape of prairies, grasslands, forests, riparian corridors, wetlands, lakes, and various other lentic and lotic waters (Figure 4-2). Topography dictates the boundaries of watersheds and the flow of water (Figure 4-3). Fragments of native habitat are interspersed in a largely agricultural environment. The area falls within the Northwestern Glaciated Plains, Northern Glaciated Plains, Lake Agassiz Plain, Northern Minnesota Wetlands, Northern Lakes and Forests, and North Central Hardwood Forests ecoregions (Omernik 1987). Unique features include the prairie pothole wetlands, which attract millions of breeding birds and a variety of other aquatic species, and tallgrass prairie, which formerly dominated the Northern Glaciated Plains and supports distinct communities of plants and animals. Since the 1780's, North Dakota and Minnesota have lost approximately 49% and 42% of their wetland acreage, respectively (Dahl 1990). Likewise, these states have lost over 70% of prairie habitat to agriculture and other development (Samson and Knopf 1994). Species diversity generally increases with habitat area and habitat diversity, such that the loss or degradation of habitat may result in local extirpations of species. Habitat alteration and the creation of monotypic landscapes have reduced biodiversity in the Red River Valley region relative to historical conditions (U.S. Fish and Wildlife Service 2005a). Not only are many native species declining in number, but a number of exotic and invasive species have been introduced. Invasive species can out-compete native plants and turn habitat into monocultures of little or reduced value to animals (see also USGS 2005a).

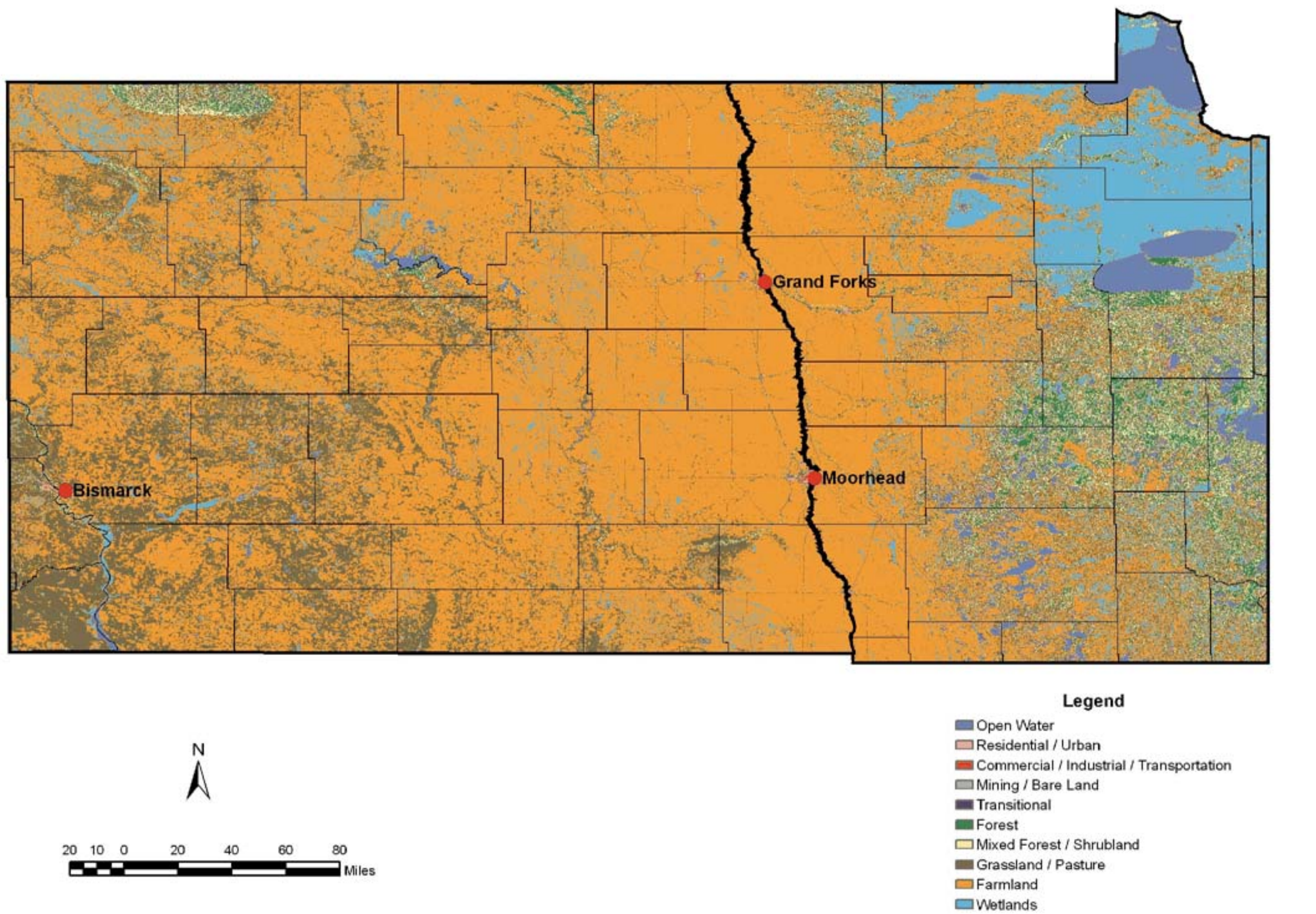


Figure 4-2a. Land cover of the Red River Valley region.

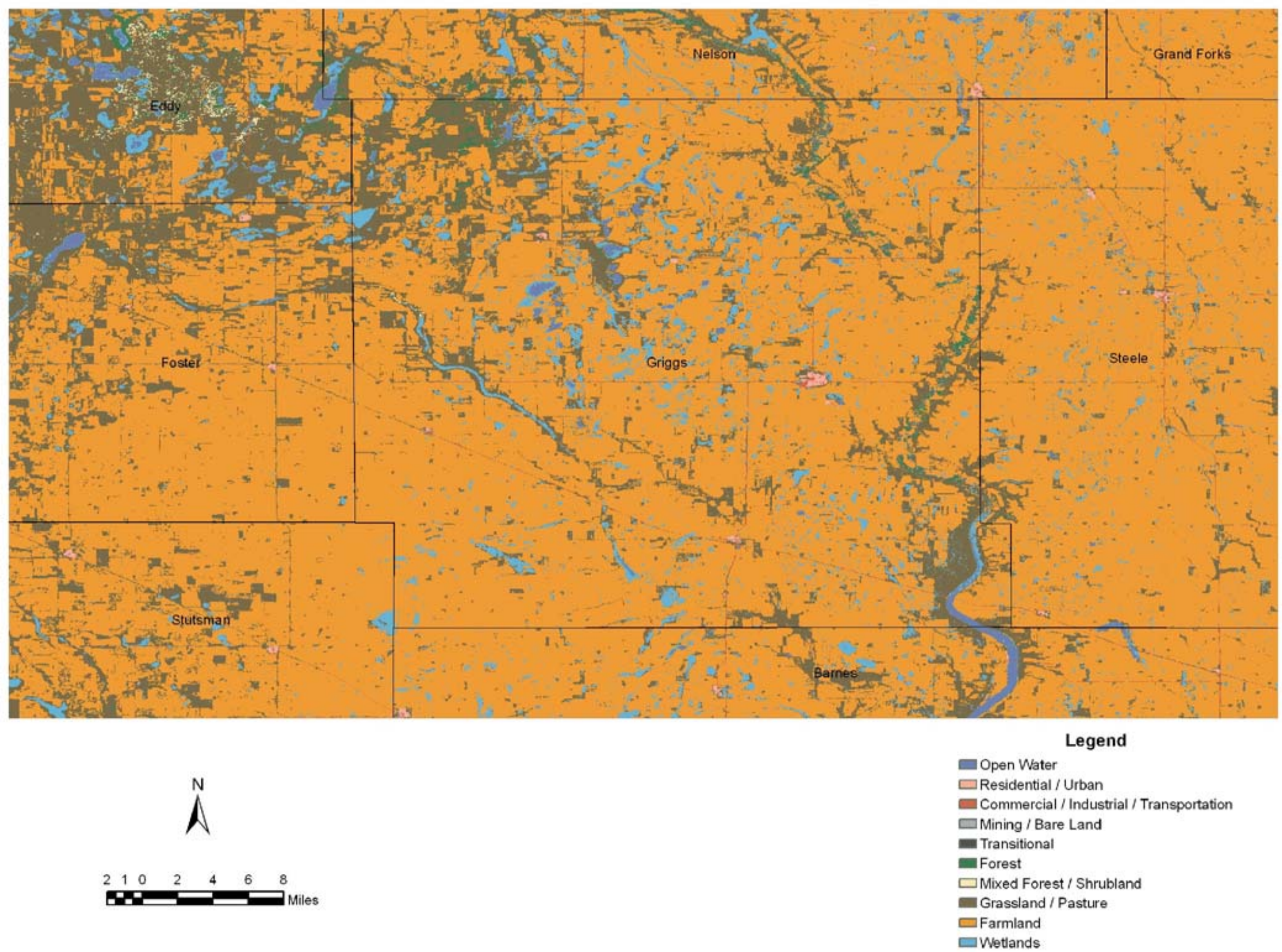


Figure 4-2b. Land cover of Griggs County, ND.

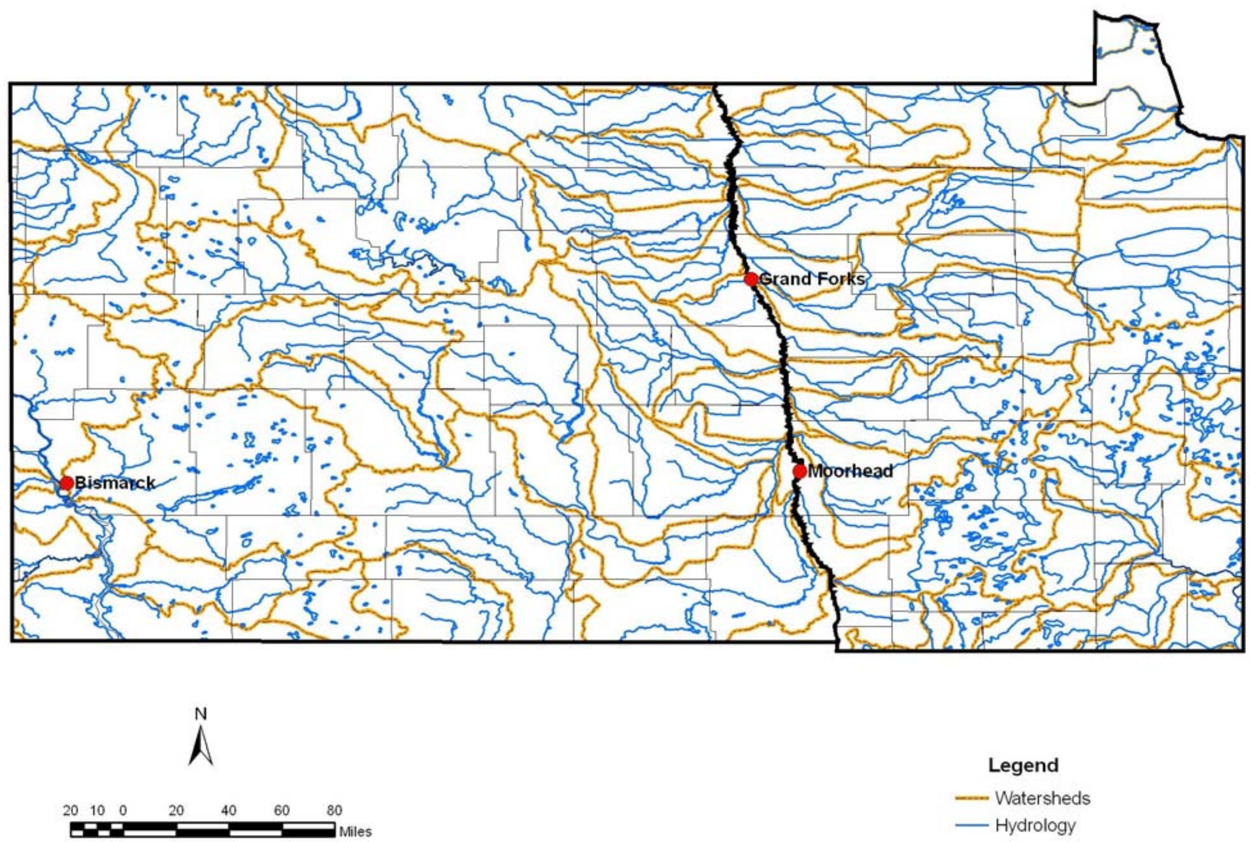


Figure 4-3. Watersheds and hydrology of the Red River Valley region.

Eastern North Dakota and western Minnesota are dotted with thousands of wetlands (Figures 4-4, 4-5a,b). There are many different types of wetlands, including wet meadows, fens, bogs, marshes, and swamps, and wetlands can be temporary, seasonal, or semi-permanent (U.S. Fish and Wildlife Service 2005a). Wetlands are among the most species-rich habitat types on earth and contain rare species found nowhere else. Many of the region's rare plant species occur in wetlands. In addition to providing habitat for plants and wildlife, wetlands have a number of functions and values beneficial to human society. Benefits of wetlands include stormwater storage, shoreline buffering during high water events, water filtration and the sequestration of contaminants, and resource extraction opportunities (e.g., hunting). Wetlands vary greatly in size from less than an acre to thousands of acres, Even the smallest of wetlands, however, confer benefits. A pool of water the size of a dinner table can support a productive community of algae, zooplankton, aquatic invertebrates, and amphibians. The loss of wetlands has been linked with increased flooding and the local extirpation of wetland-dependent species. For example, drainage activities in Minnesota have been associated with damaging summer floods becoming more common (U.S. Fish and Wildlife Service 2005a).

Figure 4-4. Wetlands of the USFWS Chase Lake Wetland Management District, Stutsman County, North Dakota. Photo credit: USFWS.

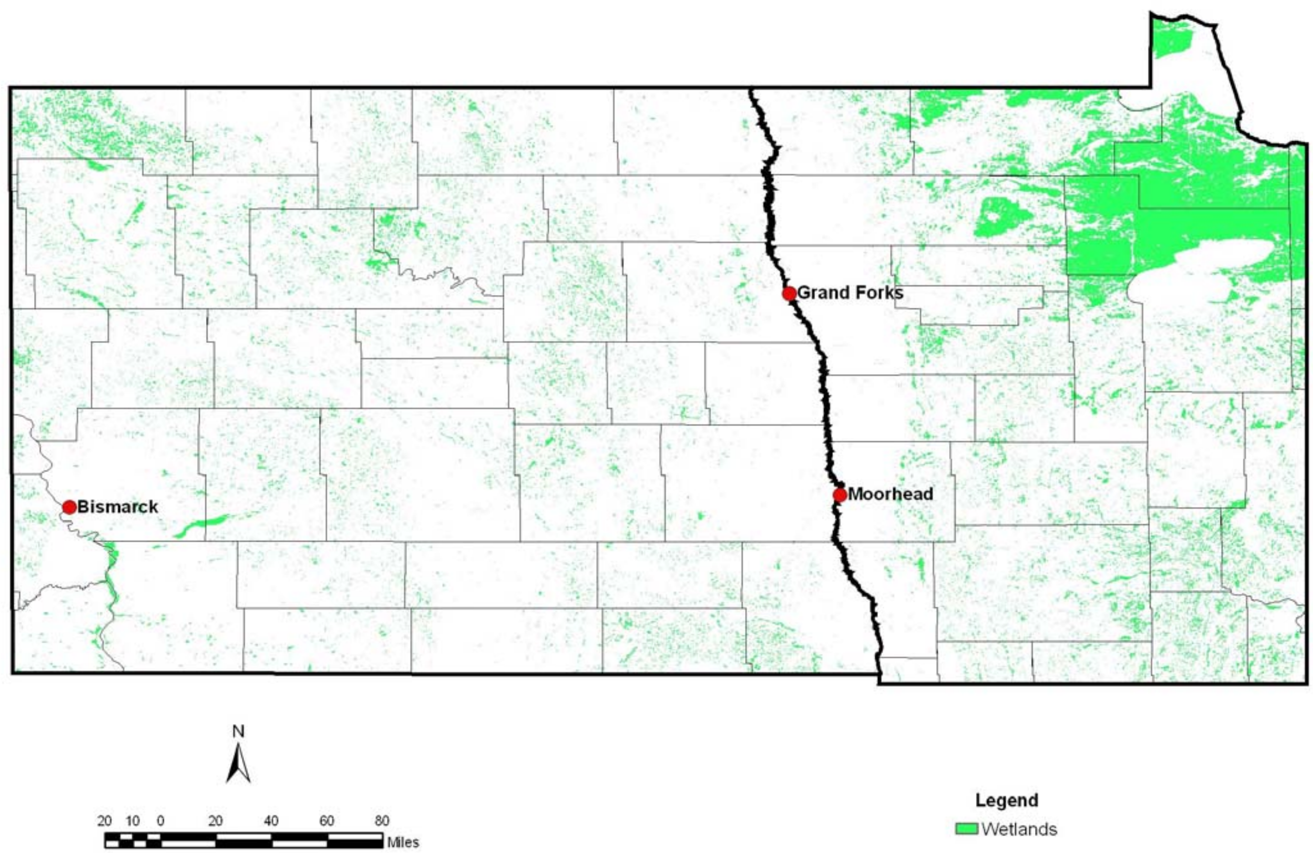


Figure 4-5a. Wetlands of the Red River Valley region.

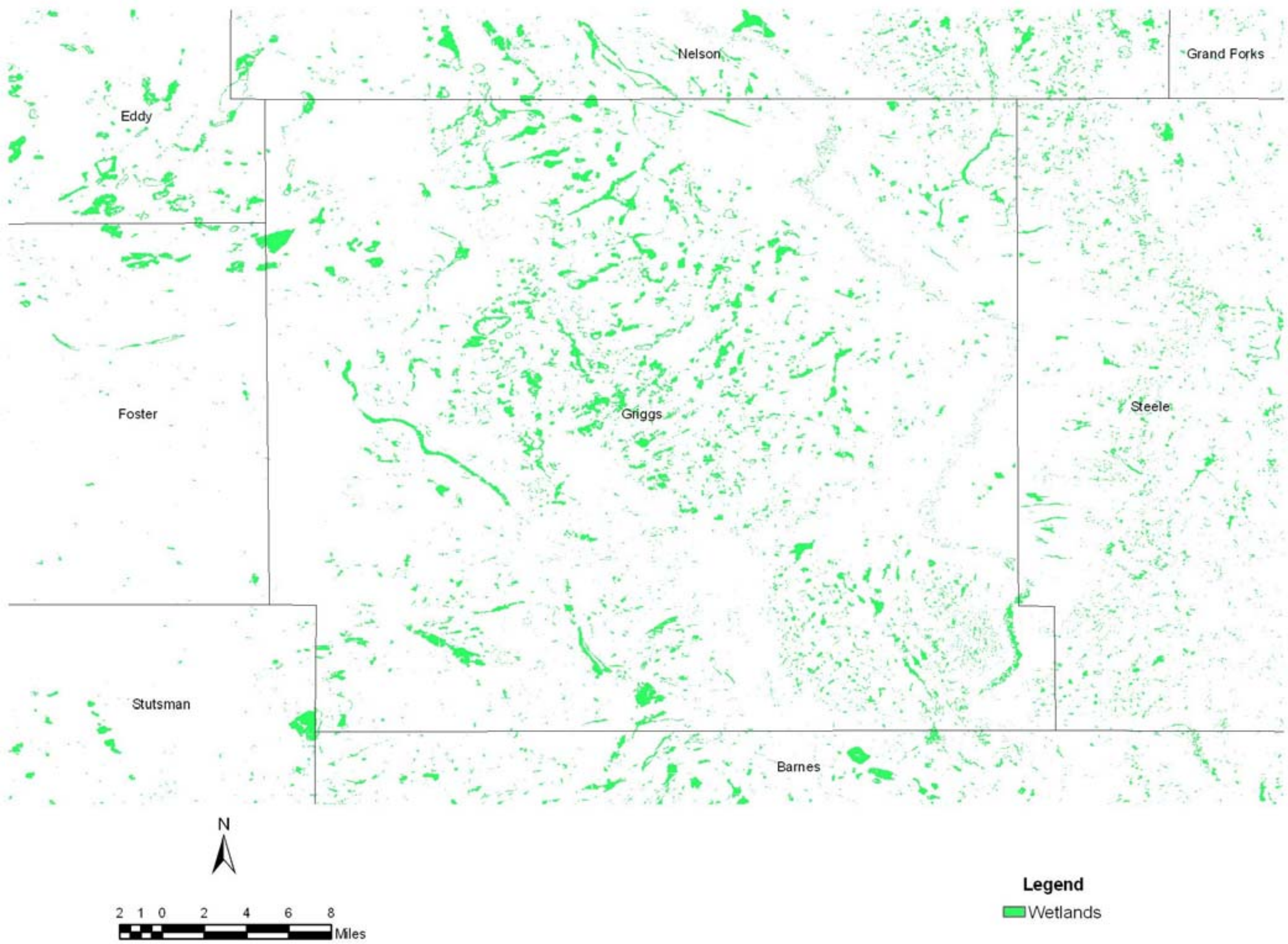


Figure 4-5b. Wetlands of Griggs County, ND.

Pipeline construction may cross wetlands (U.S. Fish and Wildlife Service 2005a), although the extent of effects associated with these crossings will vary among the different Action Alternatives and will be influenced by final pipeline route and habitats intercepted. Predicting the spatial extent of wetland crossings is incompletely characterized in the literature, since the technology used to generate wetland coverage maps cannot always detect wetlands that are shallow, dry, or forested. Hence, the minimum mapping-unit size is variable (Kudray and Gale 2000). Small and ephemeral wetlands can be missed, and these may be incompletely evaluated with respect to effects associated with pipeline crossings. For example, the most common wetland type in North Dakota is temporary wetlands, which are often less than 1 acre in size, less than 1 foot deep, and often dry in the summer months, when pipeline construction may occur (U.S. Fish and Wildlife Service 2005a). Habitat assessments for the Red River Valley Water Supply Project DEIS were based on a 400 foot-wide corridor (U.S. Fish and Wildlife Service 2005a), and mosaic wetlands having footprints less than this width may not be fully characterized, particularly if surveys and construction occur when shallow wetlands are dry and covered with vegetation (Figure 4-6). Construction activity will disturb wetlands and other habitats encountered when pipelines are buried and supporting infrastructure is built. Recovery and restoration of disturbed habitats should be incorporated into full designs as those are developed to minimize adverse effects associated with construction activities (U.S. Fish and Wildlife Service 2005a).

Figure 4-6. A dry, ephemeral wetland that may be overlooked by mapping technology and land surveyors. Photo credit: Restoration Resources, Twelve Bridges Seasonal Wetland & Vernal Pool Project.

Minimizing disturbance effects and alteration of northern prairie habitats may be critical factors in developing full designs for any of the Action Alternatives. While water development projects are only a single source of habitat alteration, minimizing short-term and long-term effects associated with construction may be accomplished early in the full design phase of the project. For example, tallgrass, mixed-grass, and shortgrass prairies of the northern Great Plains are historically uncultivated lands dominated by grasses and forbs, and contain a unique assemblage of plants and animals (Figure 4-7), but because of the loss of habitat associated with a variety of anthropogenic activities (e.g., agriculture, growth of regional population centers, including increased commerical and industrial developments), many plant and animal species associated with prairies have declined (Samson and Knopf 1994). Much of the native prairie that remains in the Red River Valley region is in North Dakota's Sheyenne National Grasslands, and smaller fragments occur along the proposed pipeline routes (U.S. Fish and Wildlife Service 2005a). Recovery from pipeline construction would depend on whether native prairie plants that were re-seeded or colonized naturally could outcompete other plant species, and whether prairie-dependent animal species were available to recolonize the area.

Figure 4-7. Prairie plants in North Dakota. Photo credit: North Dakota Tourism/Dawn Charging.

Change in land cover along pipeline routes may occur as a result of implementation of any of the Action Alternatives. Within the context of risk management, the spatial and temporal extent of changes depend on, e.g., whether permanent structures or roads are constructed, the success of restoration efforts or natural colonization, the type of maintenance done on the right-of-way, and whether pipeline or other infrastructual failures occur during in-service lifetime. For example, as water systems age, leaking pipelines may supplement water inflows to existing wetlands or possibly enhance or create wetlands in low-lying areas. The addition of water could also increase wetland area and lengthen the hydroperiod. Some wetlands may become permanent, if leaks are not detected and repaired. Linked to these potential changes in water regime, plant species composition may shift, if the seasonal patterns of wetting and drying are disturbed, or if the water chemistry changes because pipeline water quality differs from wetland water quality. Conversely, surface drainage may be altered, if pipeline construction reduces the number or size of wetlands and if water inflows associated with pipeline failures surpass the holding capacity of the remaining wetlands. Presumptive changes related to surface flows, however, illustrates how recovery and restoration of construction areas may be incorporated in the full design phase of any of the Action Alternatives. Additionally, developing O&M plans for the pipeline and supporting infrastructure would reduce, if not minimize, adverse effects associated with any water transmission system, although these activities may have their own effects on land cover, depending on how, e.g., access to pipeline and pipeline-related infrastructure is developed.

4.2.2 Soils

The soils of eastern North Dakota and western Minnesota developed over glacial sediments and residuum from marine and continental sediments (Bluemle 1977). The region has undergone several glacial advances and retreats, and has a flat to gently rolling topography because it was once covered by Lake Agassiz (Schwartz and Thiel 1954). Soil is a product of complex interactions among parent materials, relief, biological activity, climate, and time (Soil Conservation Service 1975). Soil has numerous properties, including color, pH, water holding capacity, cation exchange capacity, organic matter content, and texture. These properties are used to classify soils into different soil types, and hundreds of soil types exist. For example, 84 soil types have been identified in Minnesota's Roseau County (Potts 2002). Soils both affect and are affected by the environment. Because of their different properties, soils vary in their response to disturbance and in the type of living organisms and land uses that they can support (Potts 2002). Soils can be used to determine drainage class (Simonson and Boersma 1972), hydrological conditions (Miller et al. 1985), and water table fluctuations (Daniels et al. 1971).

Texture is one of the soil properties most influential on the movement and fate of water in soil. The parent material determines soil texture, which in turn affects soil drainage and permeability (i.e., the ease with which water moves through the soil) (Potts 2002). Texture refers to the relative proportions of sand, silt, and clay in soil. There are several textural classes (in order of increasing fine particle content): sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, clay (Potts 2002). These can be more broadly classified as sandy or coarse-textured (sand, loamy sand), loamy or medium-textured (sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam), and clayey or fine-textured (sandy clay, silty clay, clay) (Brown 2003). The finer the particles, the harder it is for water to penetrate, which is why water bodies often have a clay bottom. Sandy soils are typically low in organic matter content, do not retain moisture well, are rapidly permeable, and support deep-rooted plants, whereas loamy and clayey soils are more fertile, hold water well, and permit less rapid water movement (Brown 2003). The maximum permeability rates in the region are depicted in Figure 4-8. An example of soil texture heterogeneity, depicted as percent clay composition in a portion of Griggs County, ND, is shown in Figure 4-9.

Pipeline failures are more likely to occur in soils high in fine particles than those high in coarse particles because fine-textured soils expand and contract more with changes in moisture content and frost. Such soil movement and heaving put strain on pipes, potentially contributing to pipeline breaks. Released water may move quickly through soils with a coarse texture and high permeability, but pool in more clayey soil types. From a soil's perspective, vulnerability of pipelines to failure will vary among the proposed Action Alternatives because of differences, e.g., in the predominant soil textures that occur along the pipeline routes. Pipelines that intersect a heterogeneous mix of many texture types could be at greater risk than those that intersect only one or a few types, since rates of soil movement along the length of the pipeline are more likely to vary with increasing texture heterogeneity (Potts 2002).

US Department of Agriculture has quantified other soil features useful for assessing the susceptibility of pipeline to failure. For example, frost heave varies across the landscape (Figure 4-10) and tends to be greatest in areas high in clay and silt (Potts 2002). Freezing and thawing puts stress on buried pipe through the physical force of contraction and expansion. During the winter, soils are frozen more than five feet deep in some parts of the Red River Valley region (Potts 2002). Chemical forces in the soil may also stress and weaken pipe through corrosion. While any installation will necessarily followed standards pertinent to a specific pipe material, the susceptibility of uncoated steel to corrosion is a common starting point for evaluating soil corrosivity (Figure 4-11). Water released from pipeline failures could promote further damage to the pipe because the increase in soil moisture may increase the rate of corrosion and frost heave (Potts 2002).

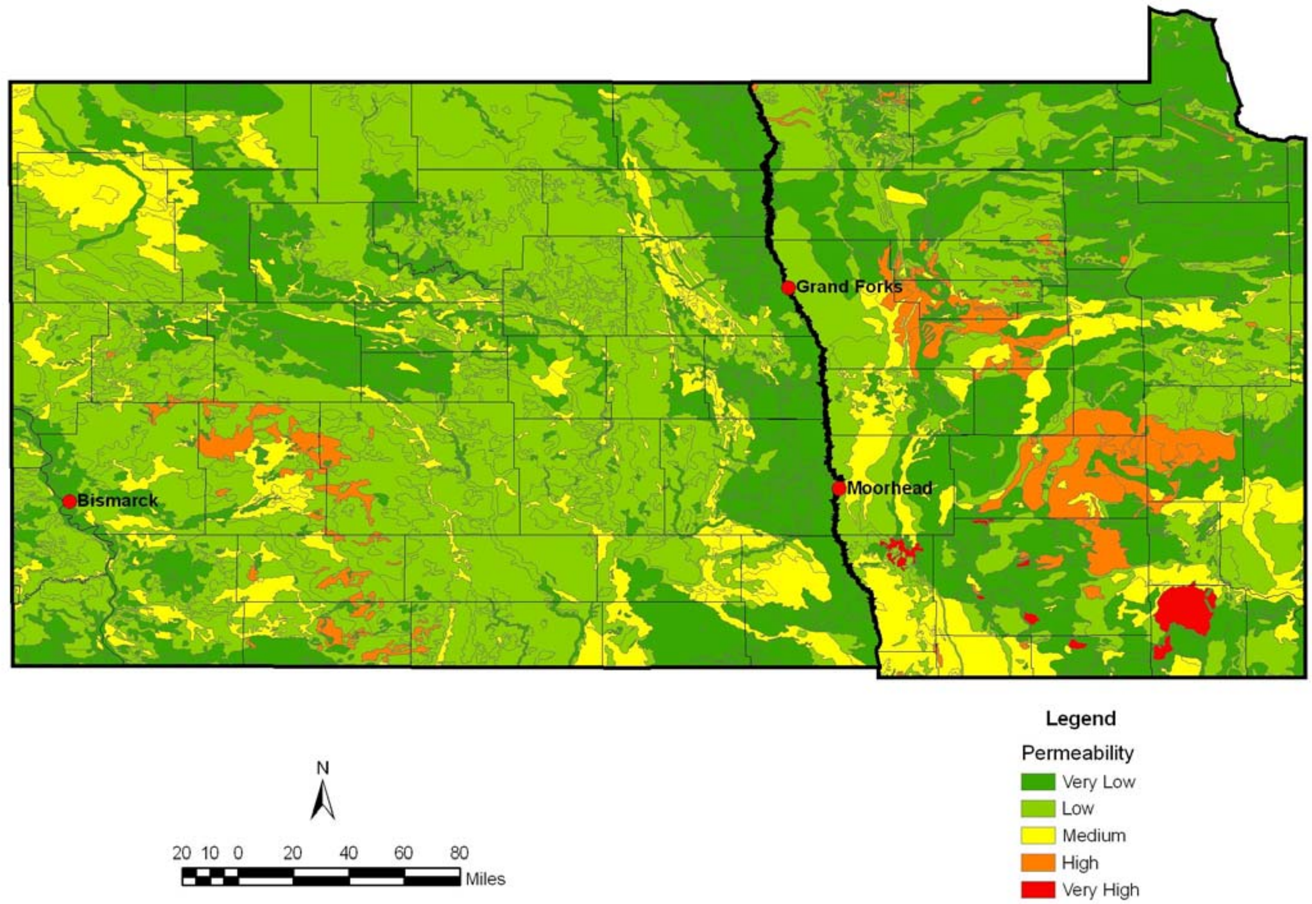


Figure 4-8. Maximum soil permeability rates (inches/hour) of the Red River Valley region.

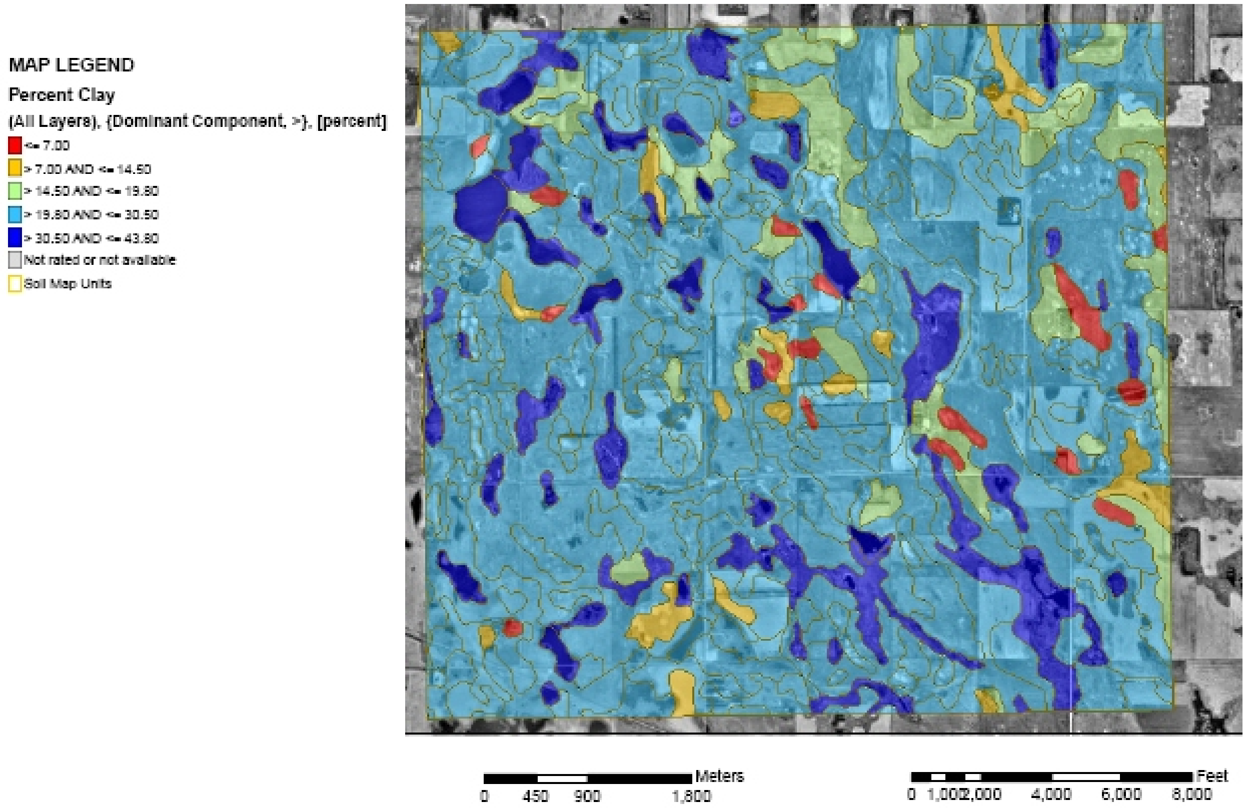


Figure 4-9. Clay composition of soil in an approximately 10,000 acre area in Griggs County, ND.

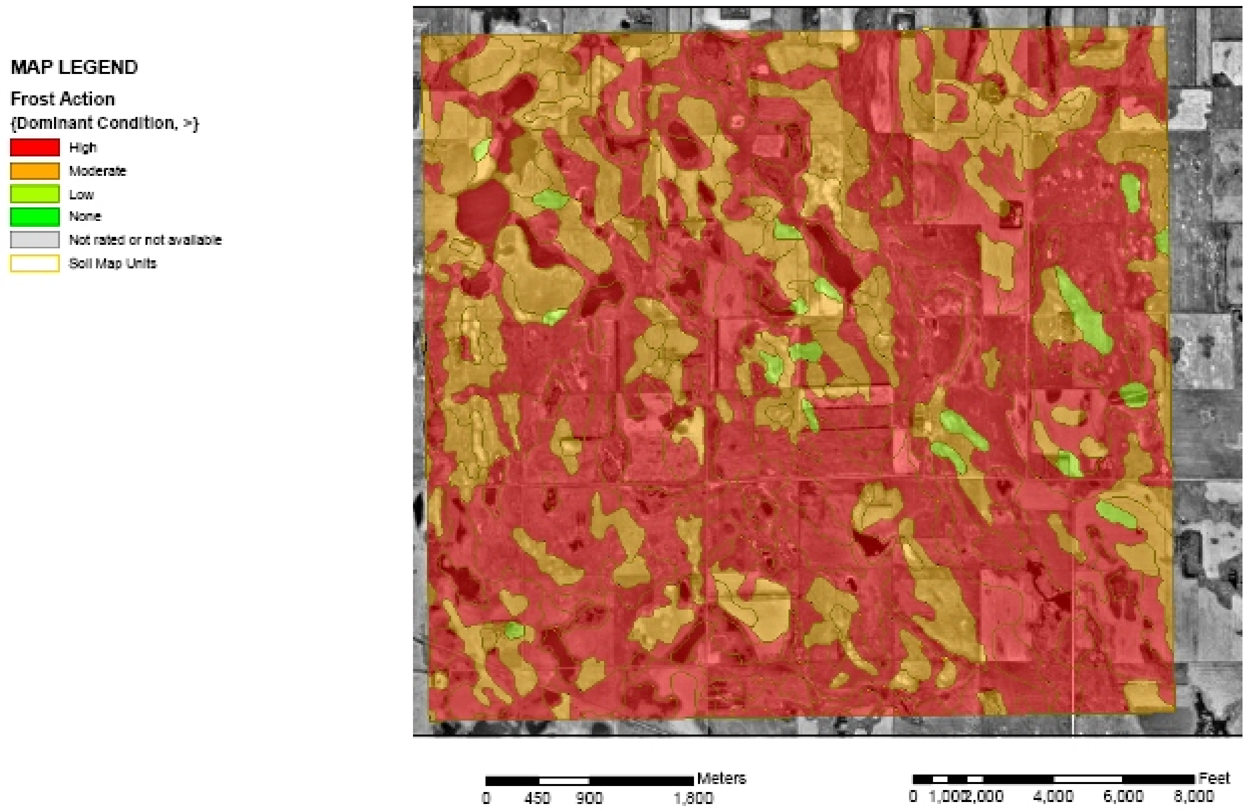


Figure 4-10. Soil susceptibility to frost heaving in an approximately 10,000 acre area in Griggs County, ND.

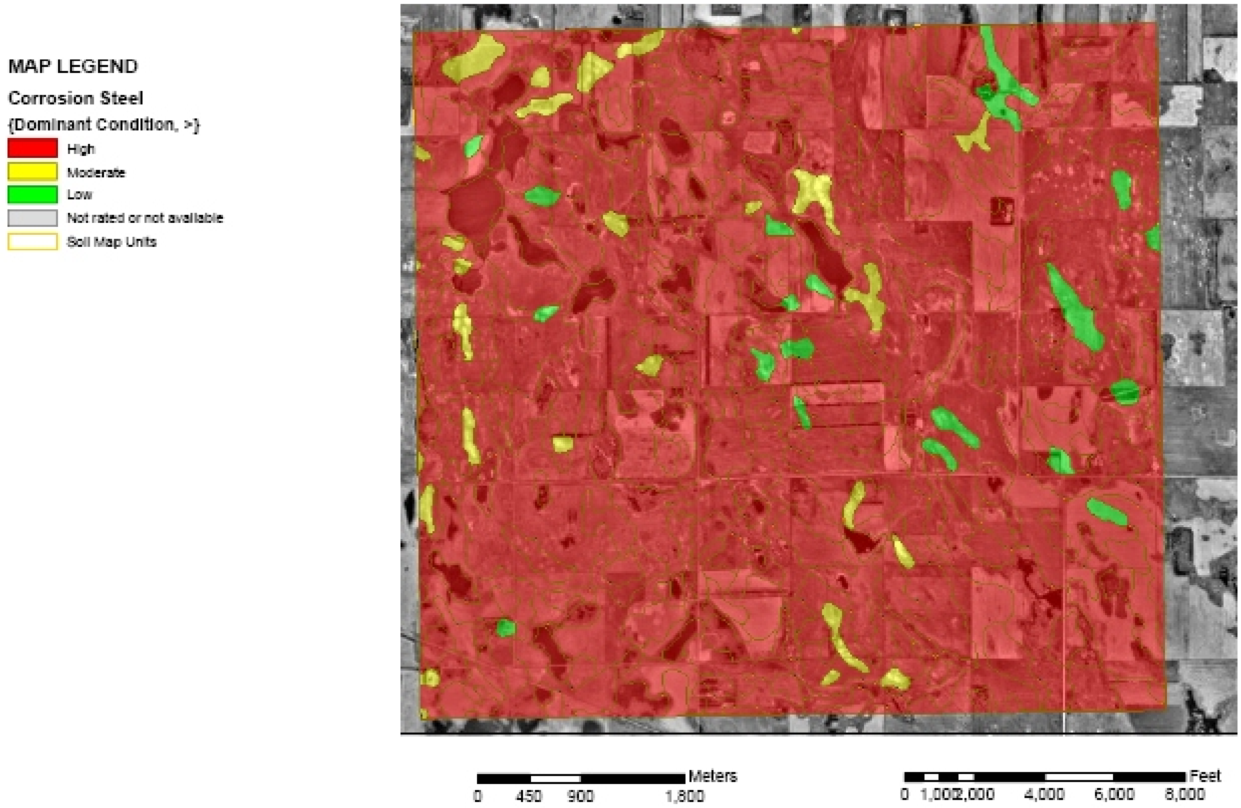


Figure 4-11. The susceptibility to corrosion of uncoated steel buried in the soil of an approximately 10,000 acre area in Griggs County, ND.

In the event of pipe leaks and breaks, trench fill and adjacent native soils are the matrices that released water would first encounter. Soils could become saturated, if water loss was extensive, and waterlogged soils characteristically display chemical and biological processes that differ from unsaturated soils. These alterations in chemical and biological processes would in turn influence the physical and chemical properties of the soil (Patrick and Mahapatra 1968). Saturation may deteriorate the existing soil structure (i.e., arrangement of particles into larger units) and reduce soil permeability and drainage. Weathering of soil and parent material would be altered by increased soil moisture, which would also affect movement of soil particles within the soil column (Potts 2002). Gleyed soils of reduced iron and other elements may develop in areas with poor drainage (Potts 2002). If pipeline reaches are characterized by chronic leaks, water loss may promote development of hydric soils in habitats initially supported by mesic and xeric soils. Depending on the extent of water loss, hydric soils of temporary wetlands may also undergo alteration, if water releases increase the length and spatial extent of the hydroperiod. Changes in soil properties and moisture regime may affect habitats and species dependent on those habitats, including human uses of those areas (Potts 2002).

4.2.3 Aquifers and Groundwater

Groundwater occurs below ground in the interstitial spaces among rock and soil, and varies with respect to water quality, e.g., it may be saline, high in minerals, and relatively depauperate, or it may be directly linked to surface wetlands and alluvial aquifers, and present a relatively diverse biological community derivative of linked habitats (Gibert et al. 1994). Groundwater is recharged from the seepage of rainwater and surface water into the ground, and is discharged to the surface as seeps and springs. Subterranean water movement occurs vertically and horizontally, and a drop of water can move miles underground. Most groundwater is located in aquifers, geologic formations that can store and transmit water to wells. Aquifers are an important source of water for rural residences, businesses, agriculture, and municipal water plants. There are two main categories of aquifers: confined and unconfined. Confined aquifers are buried below geologic materials of low permeability, such that recharge is negligible or from adjacent aquifers. Unconfined aquifers are located under materials that allow water to filter through, and may also be called surficial aquifers because they are often just below the land surface. Unconfined aquifers are usually hydraulically connected with surface water and are vulnerable to contamination because of their accessibility. Examples of unconfined aquifers include shallow alluvial, terrace, and glacial outwash deposits of sand, gravel, and silt. There are many confined and unconfined aquifers in eastern North Dakota and western Minnesota, and some aquifers have properties of both types (Reclamation 2005a). Much of the region's land surface overlays unconsolidated sand and gravel aquifers that are generally unconfined and of alluvial and glacial origin (Figure 4-12a,b). The other, less widespread aquifer type present in the region is consolidated sandstone, and those aquifers are mostly confined (Figure 4-12). Characteristics of a given aquifer vary over time and space due to changes in water availability, water demand, and other environmental factors. Different aquifers vary in permeability, composition, thickness, depth below ground, and water quality (see Table 27, Reclamation 2005a). For example, the water level of North Dakota aquifers can be as shallow as <1 foot and as deep as >100 feet below the land surface (Reclamation 2005a; Robinson and Wald 2005).

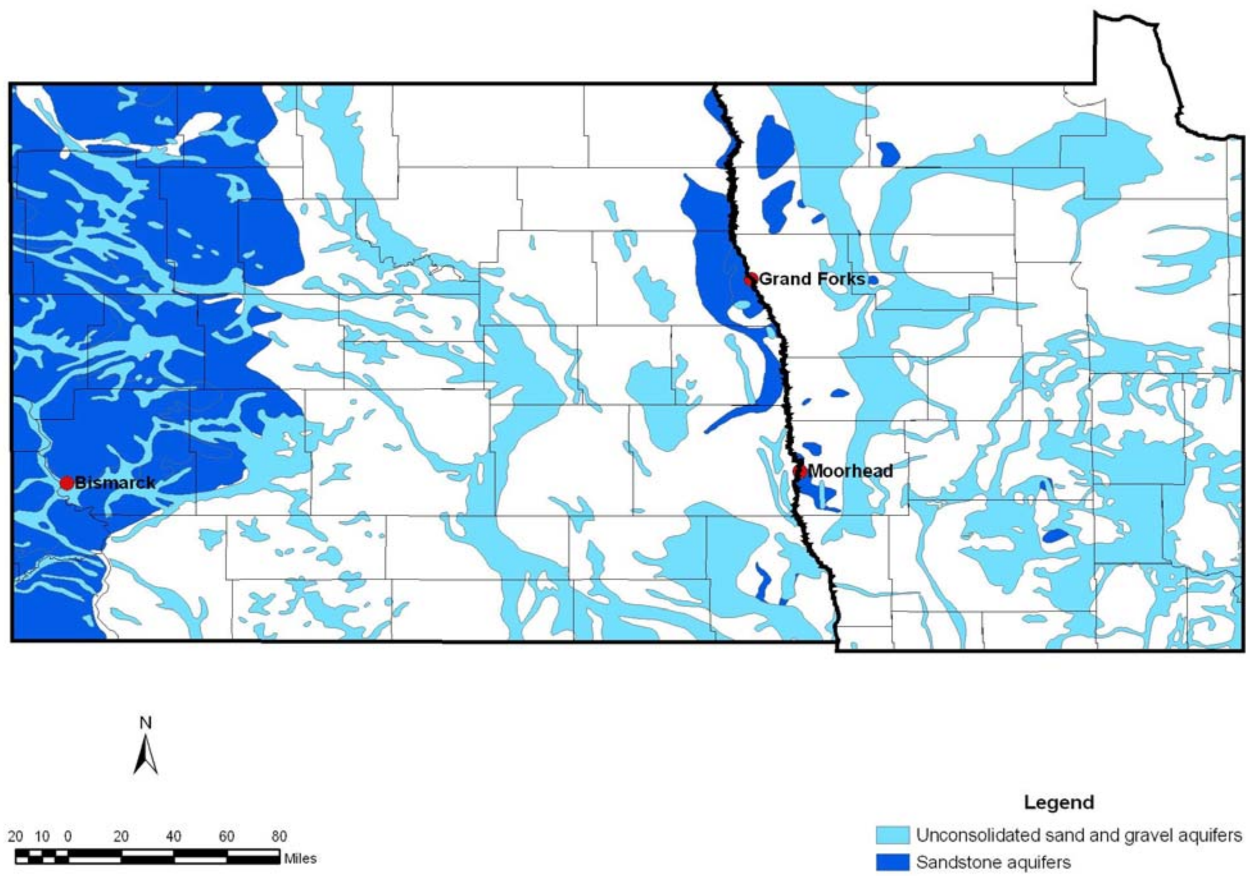


Figure 4-12a. Aquifers of the Red River Valley region.

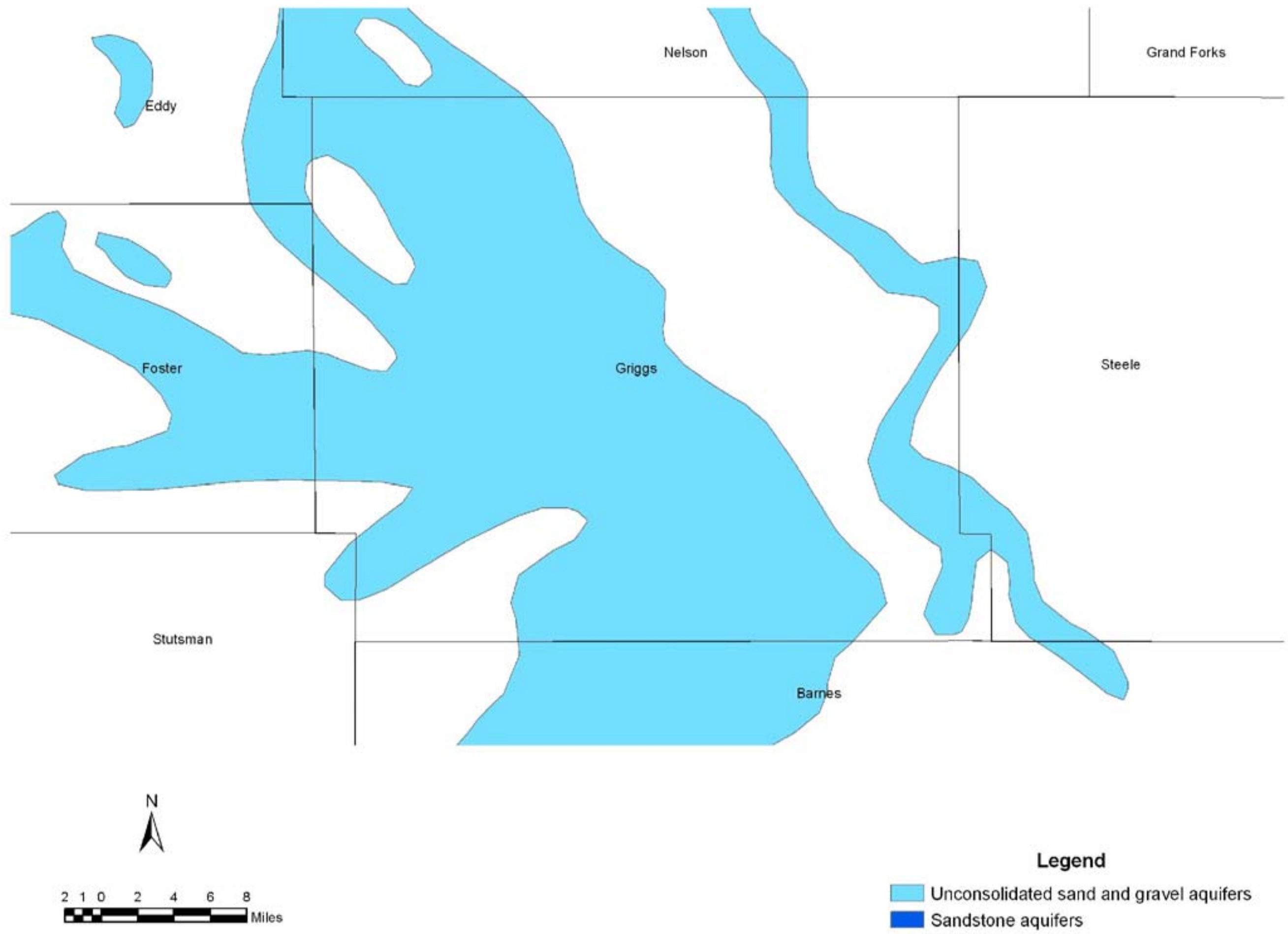


Figure 4-12b. Aquifers of Griggs County, ND.

Figure 4-13 shows the locations of the region's aquifers potentially affected by the Red River Valley Water Supply Project. The North Dakota aquifers targeted for potential development are Hankinson, Brightwood, Gwinner, Milnor Channel, and Spiritwood (U.S. Fish and Wildlife Service 2005a). Other North Dakota aquifers that may be affected by the Action Alternatives include Fordville, Horace, Page-Galesburg, Sheyenne Delta, Wahpeton Buried Valley, West Fargo North, and West Fargo South (Reclamation 2005a). In Minnesota, Otter Tail Surficial Outwash and Pelican River Sand-Plain aquifers may be tapped, and use of the Buffalo Aquifer expanded (Reclamation 2005a). Minnesota's Moorhead aquifer could also be impacted (Reclamation 2005a).

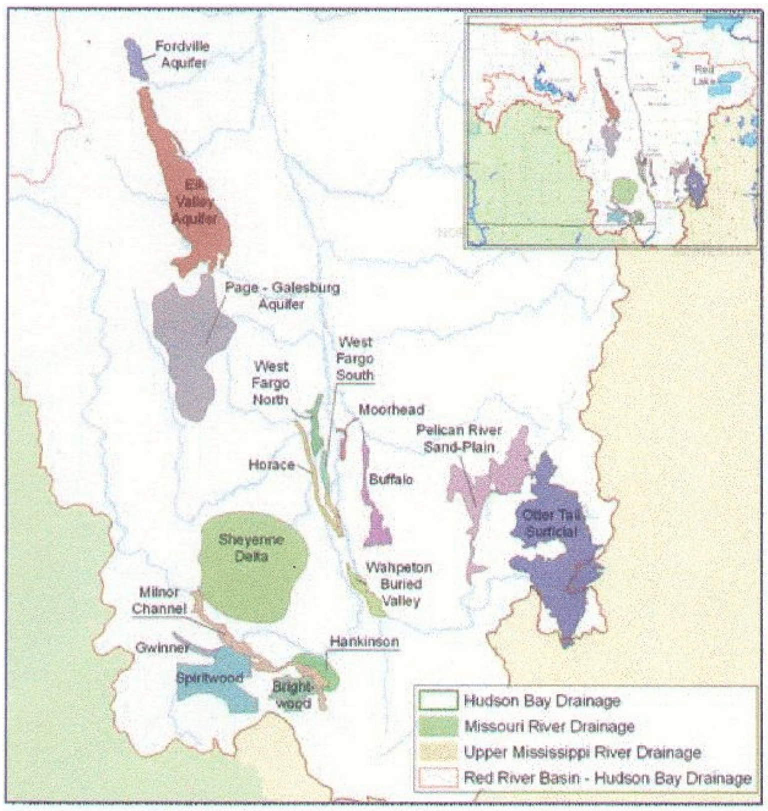


Figure 4-13. Principal aquifers that may be affected by the different Action Alternatives (reproduced from Figure 18 in DEIS).

The impact of a pipeline leak or break on groundwater would depend on a number of factors, including water table depth, soil type and permeability, geomorphology, aquifer type, leak volume, leak duration, and piped water quality. The pipeline will be buried no less than 7.5 feet below the surface, so released water will not have far to travel before hitting shallow aquifers and groundwater. In some areas, the water table is just below the soil surface (Figure 4-

14). Movement will be greatest in permeable soils high in coarse materials (e.g., sand) and low in fine-grained deposits (e.g. clay). The shallow aquifers formed of alluvial deposits and glacial outwash that are widespread in the region (Figure 4-12a,b) are largely composed of sand and gravel, and are therefore extremely permeable (Whitehead 1996). Because of the extensive nature of the permeable, shallow aquifer system, water from pipelines may be able to spread underground far distances from release locations. Piped water could be less successful in reaching aquifers that are deep and confined, depending on the underlying substrates permeability. Leaks of long duration will yield large volumes of water released to surrounding subterranean environments, potentially entering local aquifers where released water may be stored, discharged into surface water bodies, or transferred into wells.

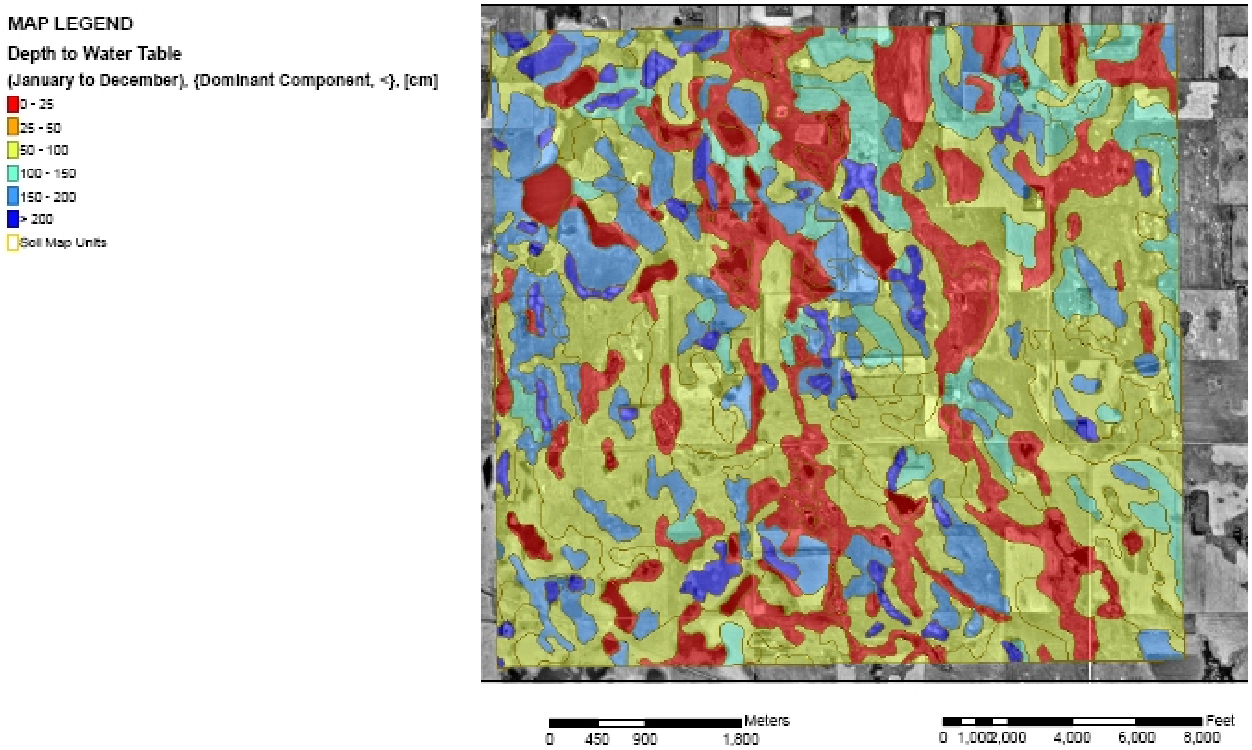


Figure 4-14. Predominant depth to water table in an approximately 10,000 acre area in Griggs County, ND.

A pipeline failure might be considered "beneficial," because released water would supplement existing groundwater resources. However, there are a number of negative effects that could occur. The water quality of treated and piped water will different from that of the groundwater near point(s) of release, and groundwater properties would change locally. Pipe corrosion potentially contributing to failure would contaminate the groundwater with corrosion products, and biofilms that develop in the pipeline could be released to groundwater. Chemicals used to treat the piped water (e.g., chlorine) and control biofilm formation (e.g., hydrogen peroxide) would enter and potentially contaminate groundwater. Water may subsequently reach chemically-contaminated sites such as landfills and dissolve and transport the contaminants. Herbicides sprayed on the right-of-way above the pipeline may likewise become more mobile and widespread due to inundation. Some aquifers are already contaminated with nitrates and other agricultural chemicals (Reclamation 2005a). Increased groundwater flow resulting from a pipeline failure may facilitate and increase the spread of agricultural contamination. Chemical and biological contaminants present in groundwater could eventually pollute the discharge areas (e.g., wells, wetlands), which may pose a health threat to humans, plants, and animals, and have significant economic costs. Economic costs could also result if a pipeline failure caused the water table to rise enough that agricultural activities (e.g., combining) could not occur or buildings were damaged.

4.2.4 Water Wells

Water wells vary greatly in level of technical sophistication, condition, depth below ground, and capacity, but all are used to obtain groundwater. Well depth varies from a few feet to hundreds of feet below the surface, depending in part on the location of the water table or aquifer targeted. Many wells are less than 100 feet deep and tap into shallow, unconfined glacial drift aquifers. Wells are pumped for domestic water supply, irrigation, livestock watering, and industrial and municipal purposes. In 2003, over 170,000 acre-feet of groundwater was used in North Dakota for irrigation (111,581 acre-feet), municipal (27,782 acre-feet), livestock (17,589 acre-feet), rural water systems/other (10,479 acre-feet), and rural domestic (5,887 acre-feet) purposes (North Dakota State Water Commission 2005). Approximately 94% of North Dakota's incorporated areas use groundwater, and groundwater is virtually the only water source in rural areas (North Dakota State Water Commission 2005). Figure 4-15a,b shows the distribution of all well types drilled by private contractors and reported in driller logs. Domestic wells are the most common and thousands are distributed across North Dakota and Minnesota (Figure 4-14). Domestic wells are typically <300 feet deep and can be quite shallow (i.e., <20 feet) (Downey et al. 1973). The depth to water is usually far less than the actual well depth (Downey et al. 1973). Irrigation and stock wells are also abundant and widespread.

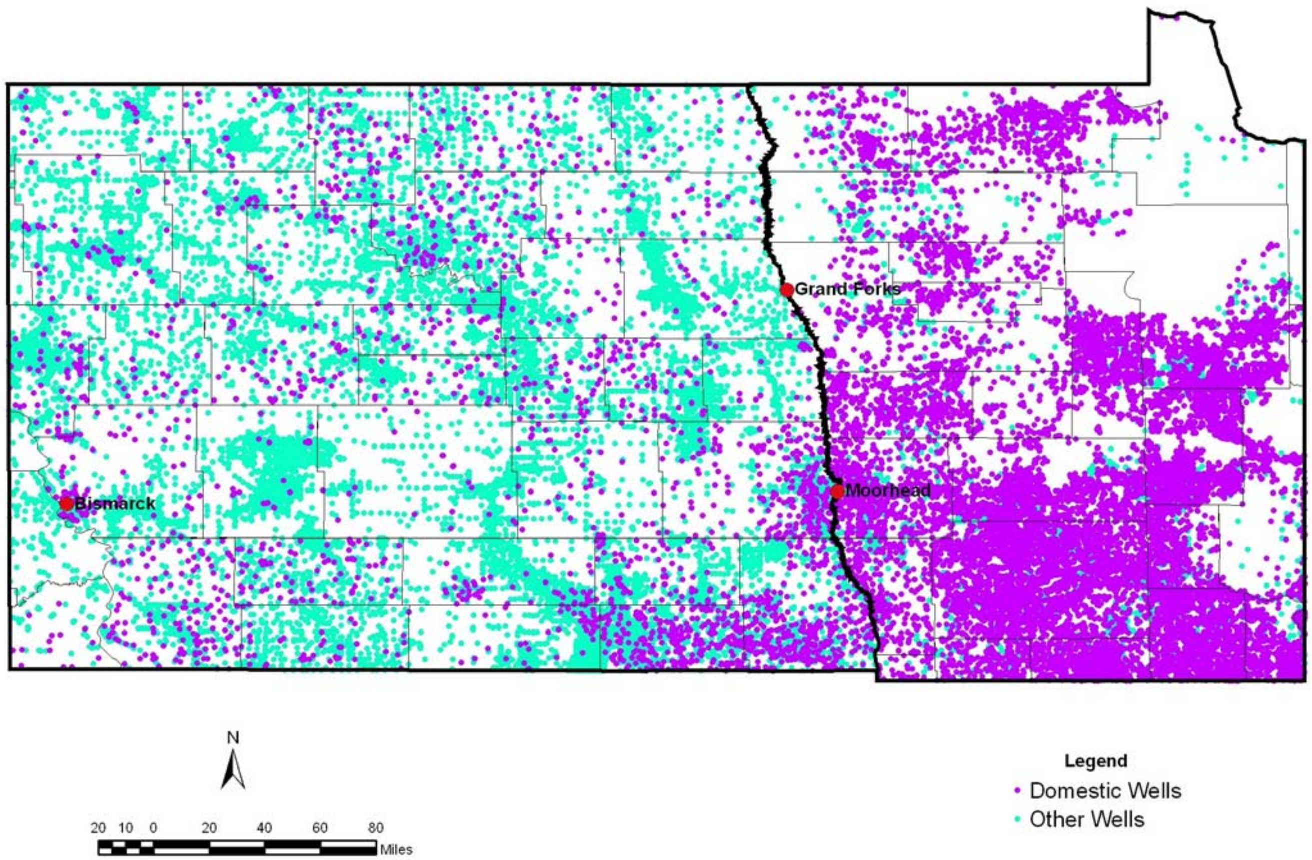


Figure 4-15a. Wells recorded from the driller logs of private contractors in the Red River Valley region.

Figure 4-15b. Wells recorded from the driller logs of private contractors in Griggs County, ND.

Water from a pipeline failure may enter groundwater or surface water and eventually reach wells. Shallow wells could be more vulnerable to infiltration than deep wells because the pipeline will be buried approximately 7.5 feet underground. However, the rate and direction of groundwater movement depends on a number of local physical factors (e.g., permeability). Groundwater can move upward, downward, and laterally, and moves from areas of higher hydraulic head to areas of lower hydraulic head. Also potentially at risk are wells that have a poorly sealed annular space between the borehole and casing, and wells with a cracked casing. Poorly constructed and poorly maintained wells are subject to infiltration by surface and vadose zone water that has not been diluted by groundwater or purified by substrate-binding processes. The effects infiltration could have on well water may vary from none to marked. In the case of no effect, the pipeline water that reaches a well will be uncontaminated, diluted by groundwater, and/or match the quality of the groundwater. However, in other instances, observable impacts may include a change in taste, odor, or quality of the well water, and might involve pipeline water contaminated with chemicals or microbial pathogens, if pipe failures occur. Common sources of groundwater and well contamination include human and animal feces, and agricultural chemicals (e.g., pesticides, fertilizers). Humans, animals, and plants that use the well water could be adversely effected (Beller et al. 1997).

4.2.5 Pipeline Failures and Interactions with Contaminants

Point and nonpoint sources of pollution occur throughout eastern North Dakota and western Minnesota, and pipeline configurations vary among Action Alternatives with respect to their location and length. Hence, unintended releases of water stemming from pipe leaks, breaks, or bursts will subsequently vary, and potential interactions of water being conveyed via pipeline with existing contamination sources may be a risk factor incorporated into full designs once developed. Depending on pipeline route, the distribution of contaminant sources relative to pipeline routes may be an important factor in future evaluations of risks associated with pipeline failures. For example, in the event of pipeline failure, water may be released and interact with soils, yielding unintended interactions with buried (e.g., septic system) or surface (e.g., fertilizer) contaminant sources. For uncontrolled releases, inundation could increase water movement within soils, potentially increasing contaminant dispersal, e.g., chemical contaminants may be desorbed from the soil matrix, then enter ground water or surface waters, depending on the interrelationships between ground water and surface water common to wetlands. Desorption and dissolution facilitates the spread of contaminants far from the original source. Contaminants vary greatly in their solubility in water; some compounds such as nitrates are highly soluble, whereas others are insoluble (e.g., some hydrocarbons). Contaminants that do not dissolve in water may still be carried from one place to another, or pool underground and serve as a chronic source of pollution to the surrounding groundwater (U.S. Environmental Protection Agency 2006). The magnitude and duration of chemical contamination depends on a number of factors, including contaminant solubility, contaminant organic carbon adsorption coefficient (K_{OC}), contaminant half-life, soil permeability, soil organic matter content, microbial and vegetation density, water flow, and groundwater depth (Seelig 1994, Hornsby 1999). The movement of pathogens through the soil depends on pore size and water velocity, and survival is a function of pH, oxygen, and temperature (Hornsby 1999). Groundwater contamination is particularly likely to occur in recharge areas overlying shallow aquifers, because there is less of a chance for filtration before the contaminants reach the groundwater (Seelig 1994). Soils high in organic matter and fine-grained particles will attenuate contaminants more so than sandy soils with little organic matter (Seelig 1994). Water movement rates will also be slower in fine-grained soils. The effects of a pipeline failure will be site-specific, because of the complex nature of the location and type of contaminants present in the region, and the spatial variation of environmental properties that could affect contaminant movement and toxicity.

4.2.6 Protected Areas

There are many private, state, and federal protected areas that occur across the region's landscape (Figure 4-16a,b). These areas provide valuable resources for wildlife, plants, and other organisms, and offer a level of protection that may not exist on surrounding properties. In North Dakota, the Parks and Recreation Department manages state parks and nature preserves, and has registered over fifty private sites in the Natural Areas Registry (North Dakota Parks and Recreation Department 2003). The North Dakota Game and Fish Department oversees the state's wildlife management areas (WMAs) and the North Dakota Forest Service controls the state forests. In Minnesota, the Department of Natural Resources is responsible for the state parks, recreation areas, forests, scientific and natural areas (SNAs), and WMAs. Federal government landowners in the region include the U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (USFWS), Department of Defense (USDOD), Bureau of Reclamation (Reclamation), and Bureau of Indian Affairs (USBIA). The USFS parcels are National Grasslands sites. The USFWS owns national wildlife refuges, a national fish hatchery, waterfowl production areas, and various easements on private property. The USDOD has an air force base in the Red River Valley, and the Corps of Engineers and Reclamation manage large reservoirs. Native American reservations are among the largest protected tracts and contain important cultural and natural resources. Several private organizations also own protected areas in the region, and The Nature Conservancy (TNC) is one of the biggest landowners.

Table 4-3 (North Dakota) and Table 4-4 (Minnesota) list by county the protected areas that are owned by the above-mentioned landowners and occur in counties crossed by proposed pipeline routes. Table 4-5 (North Dakota) and Table 4-6 (Minnesota) list by Action Alternative the protected areas that occur in counties crossed by proposed pipelines. These tables do not include USFWS easements or other government or private landholdings not specifically mentioned above. However, the number of USFWS easements potentially affected by each Action Alternative has been reported elsewhere (U.S. Fish and Wildlife Service 2005a).

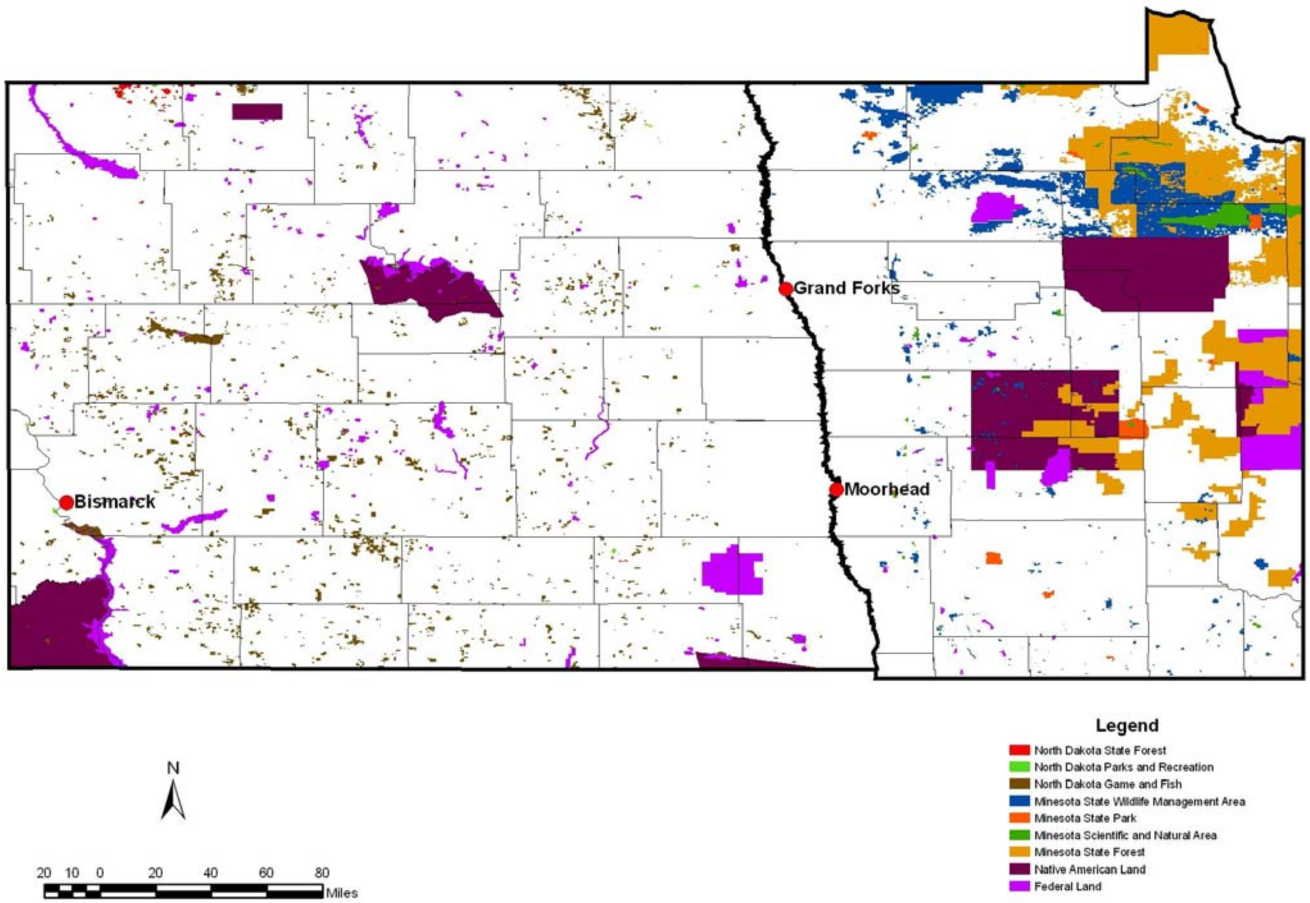


Figure 4-16a. State and federal government protected areas in the Red River Valley region.

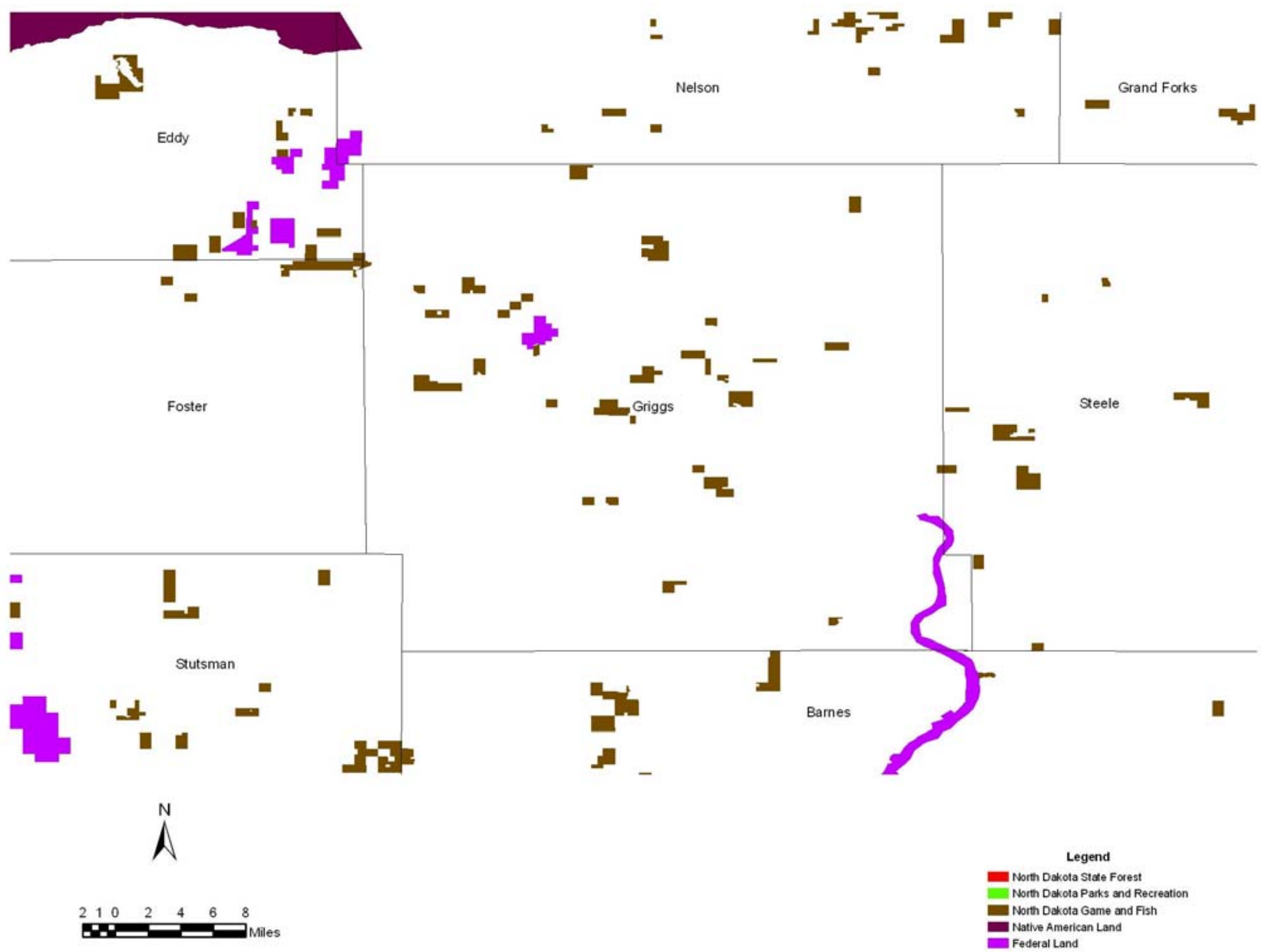


Figure 4-16b. State and federal government protected areas Griggs County, ND.

Table 4-3. Private, state, and federal protected areas in North Dakota counties crossed by proposed pipeline routes.

[a = GDU Import Pipeline; b = GDU Import to Sheyenne River; c = GDU Water Supply Replacement Pipeline; d = Lake of the Woods; e = Missouri River Import to Red River Valley; f = North Dakota In-Basin; g = Red River Basin; NWR = National Wildlife Refuge; SNA = Scientific & Natural Area; TNC = The Nature Conservancy; USBIA = U.S. Bureau of Indian Affairs; Reclamation = U.S. Bureau of Reclamation; USDOD = U.S. Department of Defense; USFS = U.S. Forest Service; USFWS = U.S. Fish & Wildlife Service; WMA = Wildlife Management Area]

County	Action Alternatives	Protected Areas
Barnes	c,e,f	**USDOD:** Lake Ashtabula **USFWS:** Hobart Lake NWR, Stoney Slough NWR, Tomahawk NWR, Valley City National Fish Hatchery, Waterfowl Production Areas **State WMAs:** Ashtabula Rearing Pond, Clausen Springs, Koldok, Moon Lake Fishing Access, Ray Holland Marsh, Valley City
Burleigh	e	**TNC:** Davis Ranch **USFWS:** Canfield Lake NWR, Florence Lake NWR, Long Lake NWR, Waterfowl Production Areas **State WMAs:** Arena Lake, Bunker Lake, McKenzie Slough, Moffit, Oahe, Phoenix Township, Rice Lake, Robert W. Henderson, Russell Stuart, Wilton Mine
Cass	a,b,c,d,e,g	**USFWS:** Waterfowl Production Areas **State WMAs:** Erie Dam and Recreation Area, Hamilton Wills, Magnolia
Foster	a,b,c	**USFWS:** Arrowwood NWR, Waterfowl Production Areas **State WMAs:** George Karpen Memorial, Rusten Slough
Grand Forks	a,b,c,d,e,f,g	**USDOD:** Grand Forks AFB **USFWS:** Kellys Slough NWR, Little Goose NWR, Waterfowl Production Areas **State Parks:** Turtle River **State WMAs:** Ed Bry, Kellys Slough, Prairie Chicken

County	Action Alternatives	Protected Areas
Griggs	a,b,c	**USDOD:** Lake Ashtabula **USFWS:** Sibley Lake NWR, Waterfowl Production Areas **State WMAs:** Sibley Lake
Kidder	e	**USFWS:** Hutchison Lake NWR, Lake George NWR, Long Lake NWR, Slade NWR, Waterfowl Production Areas **State WMAs:** Alkaline Lake, Dawson, Frettim Township, Horsehead Lake, Lake Williams, McPhail Slough, Tappen Slough
Pembina	d	**USFWS:** Waterfowl Production Areas **State Forests:** Tetrault Woods **State Nature Preserves:** Gunlogson **State Parks:** Icelandic **State WMAs:** Clifford, Eldon S. Hillman, Eyolfson, Jay V. Wessels
Ransom	c	**TNC:** Brown Ranch, Pigeon Point Preserve **USFS:** Sheyenne National Grasslands **USFWS:** Waterfowl Production Areas **State Forests:** Sheyenne River **State Nature Preserves:** H.R. Morgan **State Parks:** Fort Ransom **State WMAs:** Englevale Slough, Fort Ransom, Mirror Pool
Richland	a,b,c,d,e,f,g	**USBIA:** Lake Traverse Indian Reservation **USFS:** Sheyenne National Grasslands **USFWS:** Waterfowl Production Areas **State Nature Preserves:** H.R. Morgan **State WMAs:** Grant Township, Mirror Pool, Mud Lake, Park Lake, Stack Slough, Swan Lake, Wild Rice
Sargent	c	**USBIA:** Lake Traverse Indian Reservation **USFWS:** Storm Lake NWR, Tewaukon NWR, Wild Rice Lake NWR, Waterfowl Production Areas **State Nature Preserves:** Head of the Mountain **State WMAs:** Crete Slough, Meszaros Slough, Taayer Lake, Tewaukon

County	Action Alternatives	Protected Areas
Sheridan	a,b,c	**TNC:** Davis Ranch **USFWS:** Sheyenne Lake NWR, Waterfowl Production Areas **State WMAs:** Lincoln Valley East, Lonetree, Old John's Lake
Steele	a,b,c,f	**USDOD:** Lake Ashtabula **USFWS:** Waterfowl Production Areas **State WMAs:** Golden Lake, Otto Spies
Stutsman	e	**Reclamation:** Jamestown Reservoir **USDOD:** Pipestem Lake **USFWS:** Arrowwood NWR, Chase Lake Wilderness, Half-Way Lake NWR, Waterfowl Production Areas **State WMAs:** Chase Lake, Kirsch Tract, Spiritwood Lake Field Station, Wetland Trust, Wimbledon
Traill	a,b,c,d,e,f	**USFWS:** Waterfowl Production Areas
Walsh	c,d	**USDOD:** Homme Lake **USFWS:** Ardoch NWR, Waterfowl Production Areas **State Parks:** Historic Elmwood **State WMAs:** C.C. Cook, Joliet Ferry, North Salt Lake
Wells	a,b,c	**USFWS:** Waterfowl Production Areas **State WMAs:** Egg Lake, Forward, Harvey Dam, Heimdal, Karl T. Frederick, Lonetree, Manfred, Robert L. Morgan, Sykeston Dam, Tree Belt, Wells County

Table 4-4. Private, state, and federal protected areas in Minnesota counties crossed by proposed pipeline routes

[a = GDU Import Pipeline; b = GDU Import to Sheyenne River; c = GDU Water Supply Replacement Pipeline; d = Lake of the Woods; e = Missouri River Import to Red River Valley; f = North Dakota In-Basin; g = Red River Basin; NWR = National Wildlife Refuge; SNA = Scientific & Natural Area; TNC = The Nature Conservancy; USBIA = U.S. Bureau of Indian Affairs; USFWS = U.S. Fish & Wildlife Service; WMA = Wildlife Management Area]

County	Action Alternatives	Protected Areas
Clay	a,b,c,e,g	**TNC:** Blazing Star Prairie SNA, Bluestem Prairie SNA, Margherita Preserve-Audubon Prairie **USFWS:** Waterfowl Production Areas **State Parks:** Buffalo River **State SNAs:** Blanket Flower Prairie, Bluestem Prairie, Felton Prairie **State WMAs:** Aspen, Barnesville, Bjornson, Clay County, Cromwell, Felton, Goose Prairie, Gruhl, Hawley, Hay Creek, Highland Grove, Hitterdahl, Interstate Highway 94, Janssen, Jeral, Magnusson, Skree, Ulen
Kittson	d	**TNC:** Norway Dunes, Wallace C. Dayton Conservation & Wildlife Area **State Parks:** Lake Bronson **State SNAs:** Lake Bronson Parkland **State WMAs:** Beaches Lake, Cannon, Caribou, Deerwood, Devils Playground, Halma Swamp, Joe River, Pelan, Percy, Skull Lake, Twin Lakes
Lake of the Woods	d	**USBIA:** Red Lake Indian Reservation **State Forests:** Beltrami Island, Lake of the Woods, Northwest Angle **State Parks:** Garden Island Recreation Area, Zippel Bay **State SNAs:** Gustafson's Camp, Mulligan Lake Peatland, Norris Camp Peatland, Pine & Curry Island, Red Lake Peatland, Winter Road Lake Peatland **State WMAs:** Angle Island, Border, Carp Swamp, Four Mile Bay, Graceton, Larry Bernhoft, North Rapid, Prosper, Rako, Red Lake, Rocky Point, Silver Creek, South Shore, Spooner

County	Action Alternatives	Protected Areas
Polk	a,b,c,d,e,f,g	**TNC:** Agassiz Dunes SNA, Glacial Ridge Project, Malmberg Prairie, Pankratz Memorial Prairie, Pembina Trail Preserve, Thorson Prairie **USFWS:** Rydell NWR, Waterfowl Production Areas **State Parks:** Red River Recreation Area **State SNAs:** Agassiz Dunes, Gully Fen, Malmberg Prairie, Pembina Trail Preserve **State WMAs:** Alvarado, Bee Lake, Belgium, Brandsvold, Burnham, Castor, Chicog, Crane, Dalea, Dorr, Dugdale, Enerson, Erskine, Godfrey, Gully, Hangaard, Hasselton, Hill River, Hovland, Kakaik, Kertsonville, Kroening, La Voi, Larix, Lengby, Liberty, Maple Meadows, Mentor Prairie, Mule John, Oak Ridge Marsh, Onstad, Pembina, Polk, Rindahl, Rosebud, Sagaiigan, Shypoke, Stipa, Tilden, Timber Doodle, Trail, Tympanuchus, Woodside
Roseau	d	**USBIA:** Red Lake Indian Reservation **State Forests:** Beltrami Island, Lost River **State Parks:** Hayes Lake **State SNAs:** Luxemberg Peatland, Pine Creek Peatland, Sprague Creek Peatland, Two Rivers Aspen Prairie Parkland, Winter Road Lake Peatland **State WMAs:** Bear Creek, Bonasa, Border, Cedar Bend, Clear River, Deer, East Branch, Enstrom, Grimstad, Hayes, Hereim, Lind, Moose Marsh, Nereson, Ondatra, Palmville, Polonia, R.C. #3, Roseau Lake, Roseau River, Rosver, South Shore, Wannaska

Table 4-5. Private, state, and federal protected areas present in North Dakota counties crossed by the proposed pipeline routes of each Action Alternative

NWR = National Wildlife Refuge; SNA = Scientific & Natural Area; TNC = The Nature Conservancy; USBIA = U.S. Bureau of Indian Affairs; Reclamation = U.S. Bureau of Reclamation; USDOD = U.S. Department of Defense; USFS = U.S. Forest Service; USFWS = U.S. Fish & Wildlife Service; WMA = Wildlife Management Area]

Action Alternatives	Protected Areas
GDU Import Pipeline	**TNC:** Davis Ranch
GDU Import to Sheyenne River	**USBIA:** Lake Traverse Indian Reservation **USDOD:** Grand Forks AFB, Lake Ashtabula **USFS:** Sheyenne National Grasslands **USFWS:** Arrowwood NWR, Kellys Slough NWR, Little Goose NWR, Sheyenne Lake NWR, Sibley Lake NWR, Waterfowl Production Areas **State Nature Preserves:** H.R. Morgan **State Parks:** Turtle River **State WMAs:** Ed Bry, Egg Lake, Erie Dam and Recreation Area, Forward, George Karpen Memorial, Golden Lake, Grant Township, Hamilton Wills, Harvey Dam, Heimdal, Karl T. Frederick, Kellys Slough, Lincoln Valley East, Lonetree, Magnolia, Manfred, Mirror Pool, Mud Lake, Old John's Lake, Otto Spies, Park Lake, Prairie Chicken, Robert L. Morgan, Rusten Slough, Sibley Lake, Stack Slough, Swan Lake, Sykeston Dam, Tree Belt, Wells County, Wild Rice
GDU Water Supply Replacement Pipeline	**TNC:** Brown Ranch, Davis Ranch, Pigeon Point Preserve **USBIA:** Lake Traverse Indian Reservation **USDOD:** Grand Forks AFB, Homme Lake, Lake Ashtabula **USFS:** Sheyenne National Grasslands **USFWS:** Ardoch NWR, Arrowwood NWR, Hobart Lake NWR, Kellys Slough NWR, Little Goose NWR, Sheyenne Lake NWR, Sibley Lake NWR, Stoney Slough NWR, Storm Lake NWR, Tewaukon NWR, Tomahawk NWR, Valley City National Fish Hatchery, Wild Rice Lake NWR, Waterfowl Production Areas **State Forests:** Sheyenne River **State Nature Preserves:** Head of the Mountain, H.R. Morgan **State Parks:** Fort Ransom, Historic Elmwood, Turtle River

Action Alternatives	Protected Areas
GDU Water Supply Replacement Pipeline (continued)	**State WMAs:** Ashtabula Rearing Pond, C.C. Cook, Clausen Springs, Crete Slough, Ed Bry, Egg Lake, Englevale Slough, Erie Dam and Recreation Area, Fort Ransom, Forward, George Karpen Memorial, Golden Lake, Grant Township, Hamilton Wills, Harvey Dam, Heimdal, Joliet Ferry, Karl T. Frederick, Kellys Slough, Koldok, Lincoln Valley East, Lonetree, Magnolia, Manfred, Meszaros Slough, Mirror Pool, Moon Lake Fishing Access, Mud Lake, North Salt Lake, Old John's Lake, Otto Spies, Park Lake, Prairie Chicken, Ray Holland Marsh, Robert L. Morgan, Rusten Slough, Sibley Lake, Stack Slough, Swan Lake, Sykeston Dam, Taayer Lake, Tewaukon, Tree Belt, Valley City, Wells County, Wild Rice
Lake of the Woods	**USBIA:** Lake Traverse Indian Reservation **USDOD:** Grand Forks AFB, Homme Lake **USFS:** Sheyenne National Grasslands **USFWS:** Ardoch NWR, Kellys Slough NWR, Little Goose NWR, Waterfowl Production Areas **State Forests:** Tetrault Woods **State Nature Preserves:** Gunlogson, H.R. Morgan **State Parks:** Historic Elmwood, Icelandic, Turtle River **State WMAs:** C.C. Cook, Clifford, Ed Bry, Eldon S. Hillman, Erie Dam and Recreation Area, Eyolfson, Grant Township, Hamilton Wills, Jay V. Wessels, Joliet Ferry, Kellys Slough, Magnolia, Mirror Pool, Mud Lake, North Salt Lake, Park Lake, Prairie Chicken, Stack Slough, Swan Lake, Wild Rice
Missouri River Import to Red River Valley	**TNC:** Davis Ranch **USBIA:** Lake Traverse Indian Reservation **Reclamation:** Jamestown Reservoir **USDOD:** Grand Forks AFB, Lake Ashtabula, Pipestem Lake **USFS:** Sheyenne National Grasslands **USFWS:** Arrowwood NWR, Canfield Lake NWR, Chase Lake Wilderness, Florence Lake NWR, Half-Way Lake NWR, Hobart Lake NWR, Hutchison Lake NWR, Kellys Slough NWR, Lake George NWR, Little Goose NWR, Long Lake NWR, Slade NWR, Stoney Slough NWR, Tomahawk NWR, Valley City National Fish Hatchery, Waterfowl Production Areas **State Nature Preserves:** H.R. Morgan **State Parks:** Turtle River

Action Alternatives	Protected Areas
Missouri River Import to Red River Valley (continued)	**State WMAs:** Alkaline Lake, Arena Lake, Ashtabula Rearing Pond, Bunker Lake, Chase Lake, Clausen Springs, Dawson, Ed Bry, Erie Dam and Recreation Area, Frettim Township, Grant Township, Hamilton Wills, Horsehead Lake, Kellys Slough, Kirsch Tract, Koldok, Lake Williams, Magnolia, McKenzie Slough, McPhail Slough, Mirror Pool, Moffit, Moon Lake Fishing Access, Mud Lake, Oahe, Park Lake, Phoenix Township, Prairie Chicken, Ray Holland Marsh, Rice Lake, Robert W. Henderson, Russell Stuart, Spiritwood Lake Field Station, Stack Slough, Swan Lake, Tappen Slough, Valley City, Wetland Trust, Wild Rice, Wilton Mine, Wimbledon
North Dakota In-Basin	**USBIA:** Lake Traverse Indian Reservation **USDOD:** Grand Forks AFB, Lake Ashtabula **USFS:** Sheyenne National Grasslands **USFWS:** Kellys Slough NWR, Little Goose NWR, Hobart Lake NWR, Stoney Slough NWR, Tomahawk NWR, Valley City National Fish Hatchery, Waterfowl Production Areas **State Nature Preserves:** H.R. Morgan **State Parks:** Turtle River **State WMAs:** Ashtabula Rearing Pond, Clausen Springs, Ed Bry, Golden Lake, Grant Township, Kellys Slough, Koldok, Mirror Pool, Moon Lake Fishing Access, Mud Lake, Otto Spies, Park Lake, Prairie Chicken, Ray Holland Marsh, Stack Slough, Swan Lake, Valley City, Wild Rice
Red River Basin	**USBIA:** Lake Traverse Indian Reservation **USDOD:** Grand Forks AFB **USFS:** Sheyenne National Grasslands **USFWS:** Kellys Slough NWR, Little Goose NWR, Waterfowl Production Areas **State Nature Preserves:** H.R. Morgan **State Parks:** Turtle River **State WMAs:** Ed Bry, Erie Dam and Recreation Area, Grant Township, Hamilton Wills, Kellys Slough, Magnolia, Mirror Pool, Mud Lake, Park Lake, Prairie Chicken, Stack Slough, Swan Lake, Wild Rice

Table 4-6. Private, state, and federal protected areas present in Minnesota counties crossed by the proposed pipeline routes of each Action Alternative

[NWR = National Wildlife Refuge; SNA = Scientific & Natural Area; TNC = The Nature Conservancy; USBIA = U.S. Bureau of Indian Affairs; USFWS = U.S. Fish & Wildlife Service; WMA = Wildlife Management Area]

Action Alternatives	Protected Areas
GDU Import Pipeline GDU Import to Sheyenne River	**TNC:** Agassiz Dunes SNA, Blazing Star Prairie SNA, Bluestem Prairie SNA, Glacial Ridge Project, Malmberg Prairie, Margherita Preserve-Audubon Prairie, Pankratz Memorial Prairie, Pembina Trail Preserve, Thorson Prairie
GDU Water Supply Replacement Pipeline Missouri River Import to Red River Valley Red River Basin	**USFWS:** Rydell NWR, Waterfowl Production Areas **State Parks:** Buffalo River, Red River Recreation Area **State SNAs:** Agassiz Dunes, Blanket Flower Prairie, Bluestem Prairie, Felton Prairie, Gully Fen, Malmberg Prairie, Pembina Trail Preserve **State WMAs:** Alvarado, Aspen, Barnesville, Bee Lake, Belgium, Bjornson, Brandsvold, Burnham, Castor, Chicog, Clay County, Crane, Cromwell, Dalea, Dorr, Dugdale, Enerson, Erskine, Felton, Godfrey, Goose Prairie, Gruhl, Gully, Hangaard, Hasselton, Hawley, Hay Creek, Highland Grove, Hill River, Hitterdahl, Hovland, Interstate Highway 94, Janssen, Jeral, Kakaik, Kertsonville, Kroening, La Voi, Larix, Lengby, Liberty, Magnusson, Maple Meadows, Mentor Prairie, Mule John, Oak Ridge Marsh, Onstad, Pembina, Polk, Rindahl, Rosebud, Sagaiigan, Shypoke, Skree, Stipa, Tilden, Timber Doodle, Trail, Tympanuchus, Ulen, Woodside
Lake of the Woods	**TNC:** Agassiz Dunes SNA, Glacial Ridge Project, Malmberg Prairie, Norway Dunes, Pankratz Memorial Prairie, Pembina Trail Preserve, Thorson Prairie, Wallace C. Dayton Conservation & Wildlife Area **USBIA:** Red Lake Indian Reservation **USFWS:** Rydell NWR, Waterfowl Production Areas **State Forests:** Beltrami Island, Lake of the Woods, Lost River, Northwest Angle **State Parks:** Garden Island Recreation Area, Hayes Lake, Lake Bronson, Red River Recreation Area, Zippel Bay **State SNAs:** Agassiz Dunes, Gully Fen, Gustafson's Camp, Lake Bronson Parkland, Luxemberg Peatland, Malmberg Prairie, Mulligan Lake Peatland, Norris Camp Peatland, Pembina Trail Preserve, Pine & Curry Island, Pine Creek Peatland, Red Lake Peatland, Sprague Creek Peatland, Two Rivers Aspen Prairie Parkland, Winter Road Lake Peatland

Action Alternatives	Protected Areas
Lake of the Woods (continued)	**State WMAs:** Alvarado, Angle Island, Beaches Lake, Bear Creek, Bee Lake, Belgium, Bonasa, Border, Brandsvold, Burnham, Cannon, Caribou, Carp Swamp, Castor, Cedar Bend, Chicog, Clear River, Crane, Dalea, Deer, Deerwood, Devils Playground, Dorr, Dugdale, East Branch, Enerson, Enstrom, Erskine, Four Mile Bay, Godfrey, Graceton, Grimstad, Gully, Halma Swamp, Hangaard, Hasselton, Hayes, Hereim, Hill River, Hovland, Joe River, Kakaik, Kertsonville, Kroening, La Voi, Larix, Larry Bernhoft, Lengby, Liberty, Lind, Maple Meadows, Mentor Prairie, Moose Marsh, Mule John, Nereson, North Rapid, Oak Ridge Marsh, Ondatra, Onstad, Palmville, Pelan, Pembina, Percy, Polk, Polonia, Prosper, R.C. #3, Rako, Red Lake, Rindahl, Rocky Point, Roseau Lake, Roseau River, Rosebud, Rosver, Sagaiigan, Shypoke, Silver Creek, Skull Lake, South Shore, Spooner, Stipa, Tilden, Timber Doodle, Trail, Twin Lakes, Tympanuchus, Wannaska, Woodside
North Dakota In-Basin	**TNC:** Agassiz Dunes SNA, Glacial Ridge Project, Malmberg Prairie, Pankratz Memorial Prairie, Pembina Trail Preserve, Thorson Prairie **USFWS:** Rydell NWR, Waterfowl Production Areas **State Parks:** Red River Recreation Area **State SNAs:** Agassiz Dunes, Gully Fen, Malmberg Prairie, Pembina Trail Preserve **State WMAs:** Alvarado, Bee Lake, Belgium, Brandsvold, Burnham, Castor, Chicog, Crane, Dalea, Dorr, Dugdale, Enerson, Erskine, Godfrey, Gully, Hangaard, Hasselton, Hill River, Hovland, Kakaik, Kertsonville, Kroening, La Voi, Larix, Lengby, Liberty, Maple Meadows, Mentor Prairie, Mule John, Oak Ridge Marsh, Onstad, Pembina, Polk, Rindahl, Rosebud, Sagaiigan, Shypoke, Stipa, Tilden, Timber Doodle, Trail, Tympanuchus, Woodside

Protected areas are frequently created as refuges from disturbance associated with human activities. Species and habitats found only or predominantly on protected areas may be particularly susceptible to construction activities. For example, temporary disturbances such as the installation of pipeline may contributed to long-term edge effects linked, e.g., to abiotic changes related to temperature and soil moisture influencing vegetation recovery along the right-of-way. Edge effects can extend over 50 m from primary distribance (Gehlhausen et al. 2000). Route selection as part of full design will contribute to risk reduction associated with construction and installation activity, e.g., by minimizing incursions to sensitive areas to decrease encounters between potential receptors and unintentionally released biota.

4.2.7 Listed Species

There are nine federally listed species present in the North Dakota and Minnesota counties crossed by the seven Action Alternatives. These species are the bald eagle (*Haliaeetus leucocephalus*), Canada lynx (*Lynx canadensis*), Dakota skipper (*Hesperia dacotae*), gray wolf (*Canis lupus*), interior least tern (*Sterna antillarum*), pallid sturgeon (*Scaphirhynchus albus*), piping plover (*Charadrius melodus*), western prairie fringed orchid (*Platanthera praeclara*), and whooping crane (*Grus americana*). Table 4-7 contains the conservation status and primary habitat associations of each species. Pallid sturgeon, bald eagles, interior least terns, whooping cranes, and piping plovers (Figure 4-17) are closely associated with aquatic habitats, Dakota skippers and western prairie fringed orchids are found on prairies, and Canada lynx and gray wolf are forest species. Prairie and alkali lakes, wetlands, and shorelines have been designated as critical habitat for piping plovers in North Dakota's Burleigh, Kidder, Sheridan, and Stutsman counties, and in Minnesota's Lake of the Woods County. There are as few as four (Red River Basin alternative) and as many as eight (Missouri River Import to Red River Valley alternative) federal species that occur among the counties crossed by the different Action Alternatives (Table 4-8). Individual counties in North Dakota and Minnesota contain between one and five federally listed species (Tables 4-9, 4-10, Figure 4-18).

Figure 4-17. A piping plover wading along a shoreline. Photo credit: Peter Weber.

Table 4-7. Federally listed species that occur in counties crossed by pipeline routes specified in the Action Alternatives

Species	Federal Status	Predominant Habitat
Bald Eagle (*Haliaeetus leucocephalus*)	Threatened	mature forests near aquatic habitat
Canada Lynx (*Lynx canadensis*)	Threatened	forests
Dakota Skipper (*Hesperia dacotae*)	Candidate	wet and dry prairies
Gray Wolf (*Canis lupus*)	Threatened ([1]MN) Endangered ([2]ND)	forests
Interior Least Tern (*Sterna antillarum*)	Endangered	sandbars of rivers and reservoirs
Pallid Sturgeon (*Scaphirhynchus albus*)	Endangered	large rivers
Piping Plover (*Charadrius melodus*)	Threatened	shorelines of rivers and prairie alkali lakes
Western Prairie Fringed Orchid (*Platanthera praeclara*)	Threatened	wet prairies, sedge meadows
Whooping Crane (*Grus americana*)	Endangered	wetlands, wet prairies

[1] MN = Minnesota. [2] ND = North Dakota.

Table 4-8. Federally listed (endangered, threatened, candidate) species present in counties crossed by the proposed pipeline routes of each Action Alternative.

Action Alternative	Species Number	Species
GDU Import Pipeline	6	Bald Eagle, Dakota Skipper, Gray Wolf, Piping Plover, Western Prairie Fringed Orchid, Whooping Crane
GDU Import to Sheyenne River	6	Bald Eagle, Dakota Skipper, Gray Wolf, Piping Plover, Western Prairie Fringed Orchid, Whooping Crane
GDU Water Supply Replacement Pipeline	6	Bald Eagle, Dakota Skipper, Gray Wolf, Piping Plover, Western Prairie Fringed Orchid, Whooping Crane
Lake of the Woods	6	Bald Eagle, Canada Lynx, Dakota Skipper, Gray Wolf, Piping Plover, Western Prairie Fringed Orchid
Missouri River Import to Red River Valley	8	Bald Eagle, Dakota Skipper, Gray Wolf, Interior Least Tern, Pallid Sturgeon, Piping Plover, Western Prairie Fringed Orchid, Whooping Crane
North Dakota In-Basin	5	Bald Eagle, Dakota Skipper, Gray Wolf, Western Prairie Fringed Orchid, Whooping Crane
Red River Basin	4	Bald Eagle, Dakota Skipper, Gray Wolf, Western Prairie Fringed Orchid

Table 4-9. Federal endangered (E), threatened (T), and candidate (C) species by North Dakota county. Presence is indicated by ●

[a = GDU Import Pipeline; b = GDU Import to Sheyenne River; c = GDU Water Supply Replacement Pipeline; d = Lake of the Woods; e = Missouri River Import to Red River Valley; f = North Dakota In-Basin; g = Red River Basin]

County	Action Alternatives	Bald Eagle (T)	Dakota Skipper (C)	Gray Wolf (E)	Interior Least Tern (E)	Pallid Sturgeon (E)	Piping Plover (T)	Western Prairie Fringed Orchid (T)	Whooping Crane (E)	Total Species Number
Barnes	c,e,f	●							●	2
Burleigh	e	●			●	●	●		●	5
Cass	a,b,c,d,e,g	●		●						2
Foster	a,b,c	●					●		●	3
Grand Forks	a,b,c,d,e,f,g	●		●						2
Griggs	a,b,c	●							●	2
Kidder	e	●					●		●	3
Pembina	d	●		●						2
Ransom	c	●	●					●		3
Richland	a,b,c,d,e,f,g	●	●	●				●		4
Sargent	c	●	●	●						3
Sheridan	a,b,c	●		●			●		●	4
Steele	a,b,c,f	●								1
Stutsman	e	●	●				●		●	4
Traill	a,b,c,d,e,f	●								1
Walsh	c,d	●		●						2
Wells	a,b,c	●	●				●		●	4

Table 4-10. Federal endangered (E), threatened (T), and candidate (C) species by Minnesota county. Presence is indicated by ●

[a = GDU Import Pipeline; b = GDU Import to Sheyenne River; c = GDU Water Supply Replacement Pipeline; d = Lake of the Woods; e = Missouri River Import to Red River Valley; f = North Dakota In-Basin; g = Red River Basin]

County	Action Alternatives	Bald Eagle (T)	Canada Lynx (T)	Dakota Skipper (C)	Gray Wolf (E)	Piping Plover (T)	Western Prairie Fringed Orchid (T)	Total Species Number
Clay	a,b,c,e,g			●			●	2
Kittson	d	●		●	●		●	4
Lake of the Woods	d	●	●		●	●		4
Polk	a,b,c,d,e,f,g	●		●	●		●	4
Roseau	d	●	●		●			3

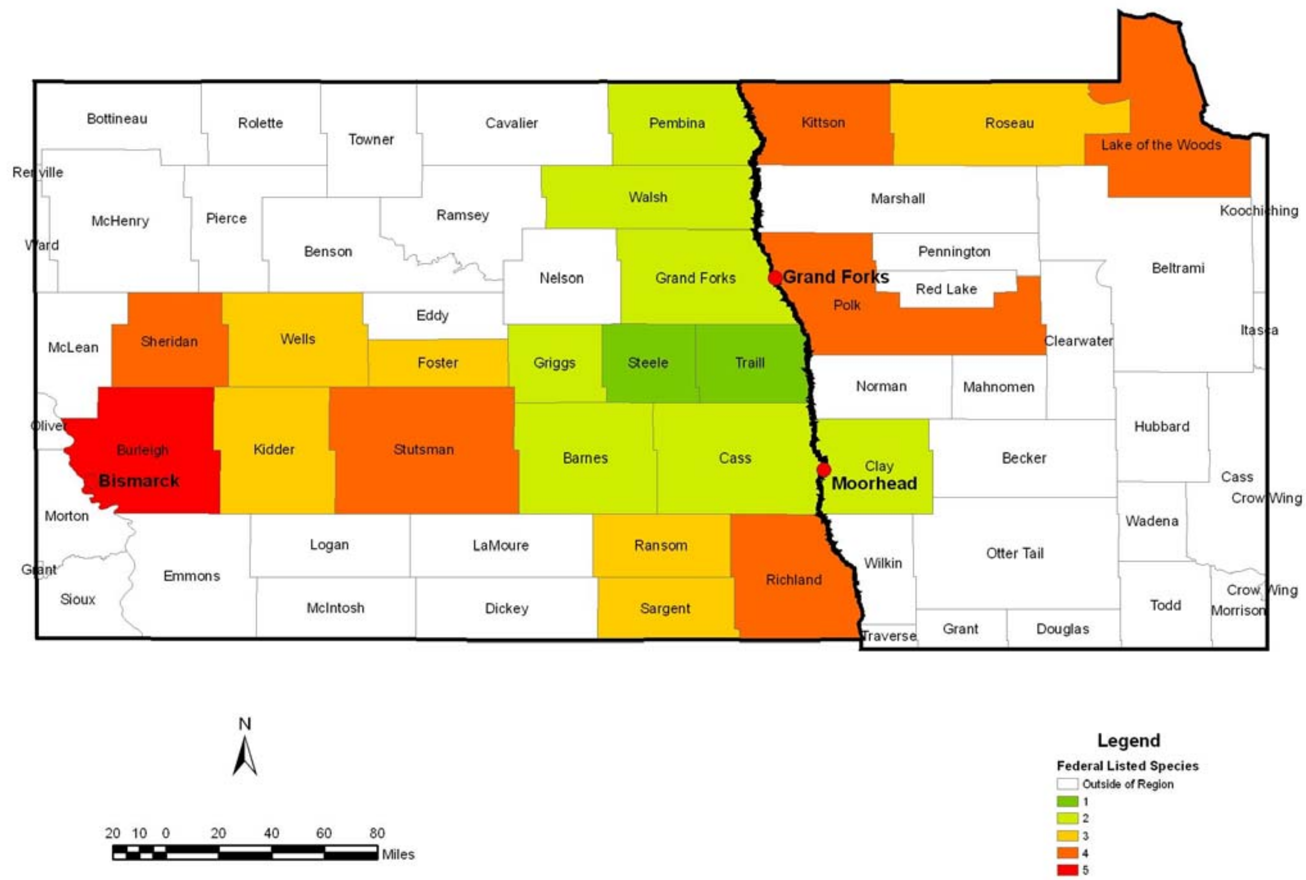


Figure 4-18. The number of federally listed species per county.

In addition to the federally listed species, there are a number of species that are considered critically imperiled (S1 Natural Heritage State Rank) or imperiled (S2 Natural Heritage State Rank) at the state level. Minnesota has an Endangered Species Statute (Minnesota Statutes, Section 84.0895) and maintains a species list codified as Minnesota Rules, Chapter 6134 (Minnesota Department of Natural Resources 1996). *Minnesota's List of Endangered, Threatened, and Special Concern Species* (Minnesota Department of Natural Resources 1996) lists 31 S1 and S2 plants and animals that occur in counties crossed by proposed pipeline routes (Table 4-11). The habitat utilized by these species includes prairie, grasslands, wet meadows, and fens (Table 4-11). Some species occur in the vicinity of (i.e., same county) one Action Alternative, whereas other species occur in the vicinity of all seven Action Alternatives (Table 4-11). The number of state critically imperiled and imperiled species per county varies from 5 (Lake of the Woods) to 15 (Polk) (Figure 4-19). The State of North Dakota does not have endangered species legislation, but the state's Natural Heritage Inventory program maintains lists of species of concern that include S1 and S2 plants (Dirk 2006a) and animals (Dirk 2006b). Seventy-one S1 and S2 species occur in North Dakota counties crossed by proposed pipeline routes, the majority of which are plants (Table 4-12). The species are associated with open habitat (e.g., prairie, grassland), wooded areas, and wet or aquatic habitat (Table 4-12). Some species are in the vicinity of only one Action Alternative, whereas other species are in the vicinity of all alternatives. The number of listed species per county varies from 0 (Traill) to 36 (Ransom) (Figure 4-19).

Table 4-11. The distribution and habitat of rare (S1, S2) Minnesota species that occur in counties crossed by proposed pipeline routes, and relevant Action Alternatives

[a = GDU Import Pipeline; b = GDU Import to Sheyenne River; c = GDU Water Supply Replacement Pipeline; d = Lake of the Woods; e = Missouri River Import to Red River Valley; f = North Dakota In-Basin; g = Red River Basin]

Species	**Counties**	**Action Alternatives**	**Predominant Habitat**
Annual skeletonweed (*Shinnersoseris rostrata*)	Polk	a,b,c,d,e,f,g	prairies, sandy areas
Assiniboia skipper (*Hesperia comma assiniboia*)	Clay, Kittson, Polk, Roseau	a,b,c,d,e,f,g	prairies
Baird's sparrow (*Ammodramus bairdii*)	Clay, Polk, Roseau	a,b,c,d,e,f,g	prairies, wet meadows
Burrowing owl (*Speotyto cunicularia*)	Clay, Polk	a,b,c,d,e,f,g	prairies, savanna
Chestnut-collared longspur (*Calcarius ornatus*)	Clay, Polk	a,b,c,d,e,f,g	prairies
Common tern (*Sterna hirundo*)	Lake of the Woods	d	lakes, rivers, marshes
Frenchman's bluff moonwort (*Botrychium gallicomontanum*)	Kittson	d	prairies
Garber's sedge (*Carex garberi*)	Kittson	d	fens, swamps, ponds
Garita skipper (*Oarisma garita*)	Clay, Kittson	a,b,c,d,e,g	prairies
Gray ragwort (*Senecio canus*)	Polk	a,b,c,d,e,f,g	grasslands
Hair-like beak-rush (*Rhynchospora capillacea*)	Clay, Polk, Roseau	a,b,c,d,e,f,g	fens, seeps
Henslow's sparrow (*Ammodramus henslowii*)	Clay	a,b,c,e,g	grasslands, meadows
Holboell's rockcress (*Arabis holboelli*)	Kittson	d	woods
Horned grebe (*Podiceps auritus*)	Kittson, Roseau	d	marshes, ponds, lakes
Indian ricegrass (*Oryzopsis hymenoides*)	Polk	a,b,c,d,e,f,g	grasslands
Loggerhead shrike (*Lanius ludovicianus*)	Clay, Polk	a,b,c,d,e,f,g	grassland, savanna
Pale moonwort (*Botrychium pallidum*)	Polk	a,b,c,d,e,f,g	grassland
Ram's-head lady's-slipper (*Cypripedium arietinum*)	Lake of the Woods, Roseau	d	marshes, woods
Red saltwort (*Salicornia rubra*)	Kittson	d	shores, seeps

Species	Counties	Action Alternatives	Predominant Habitat
Sea milkwort (*Glaux maritima*)	Kittson	d	wet meadows, seeps
Siberian yarrow (*Achillea sibirica*)	Roseau	d	woods
Small white waterlily (*Nymphaea leibergii*)	Lake of the Woods, Roseau	d	ponds, streams
Sprague's pipit (*Anthus spragueii*)	Clay, Polk, Roseau	a,b,c,d,e,f,g	prairies, wet meadows
Sterile sedge (*Carex sterilis*)	Clay, Polk, Roseau	a,b,c,d,e,f,g	fens, wet meadows
Tiger beetle (*Cicindela fulgida westbournei*)	Kittson	d	sparse vegetation, near water
Tiger beetle (*Cicindela denikei*)	Lake of the Woods	d	sparse vegetation, sand
Tiger beetle (*Cicindela limbata nympha*)	Polk	a,b,c,d,e,f,g	sparse vegetation, blowouts
Trumpeter swan (*Cygnus buccinator*)	Polk	a,b,c,d,e,f,g	ponds, lakes, marshes
Uhler's arctic (*Oeneis uhleri varuna*)	Clay	a,b,c,e,g	prairies
Whorled nut-rush (*Scleria verticillata*)	Clay	a,b,c,e,g	prairies, fens
Wilson's phalarope (*Phalaropus tricolor*)	Clay, Kittson, Lake of the Woods, Polk, Roseau	a,b,c,d,e,f,g	marshes, ponds

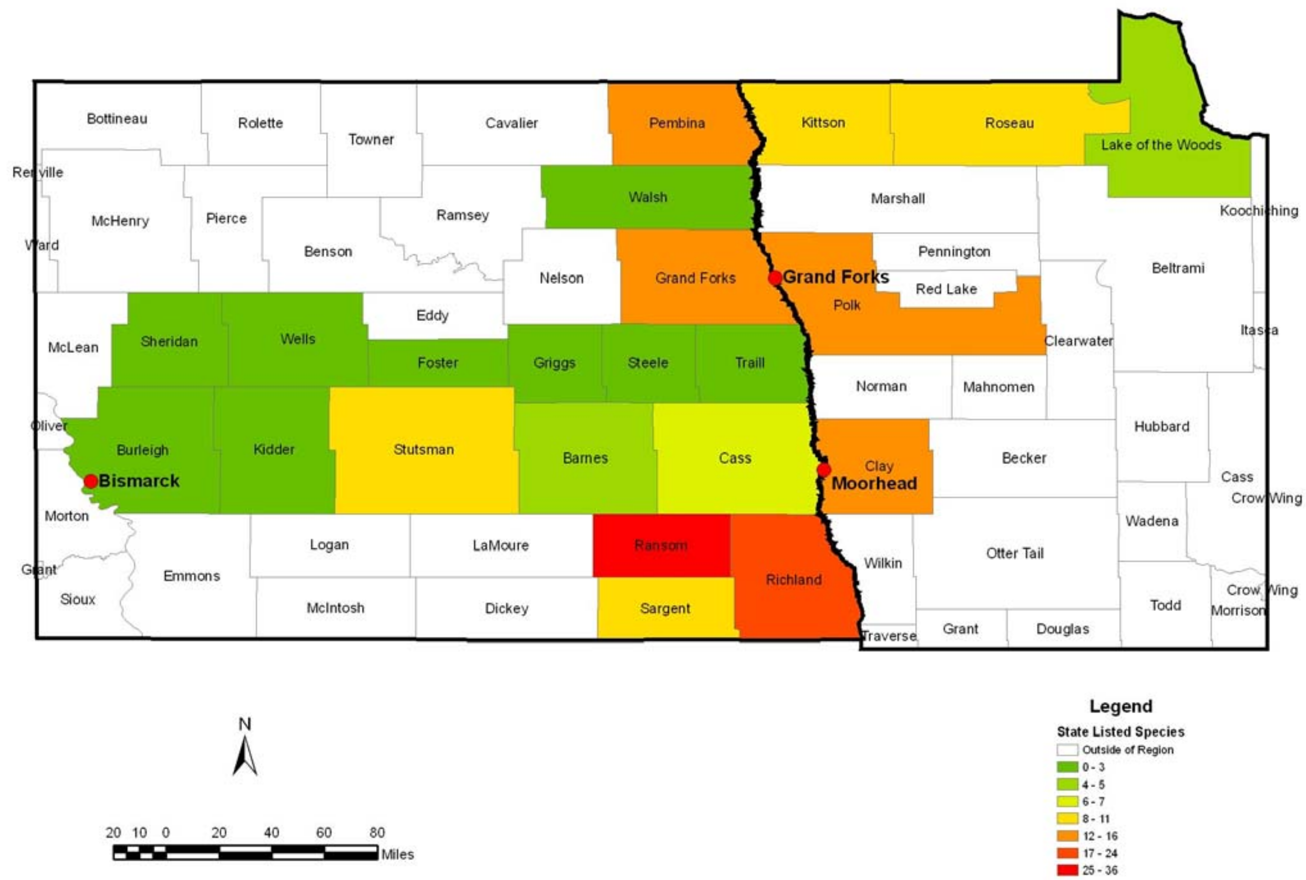


Figure 4-19. The number of state listed species per county.

Table 4-12. The distribution and habitat of rare (S1, S2) North Dakota species that occur in counties crossed by proposed pipeline routes, and relevant Action Alternatives

[a = GDU Import Pipeline; b = GDU Import to Sheyenne River; c = GDU Water Supply Replacement Pipeline; d = Lake of the Woods; e = Missouri River Import to Red River Valley; f = North Dakota In-Basin; g = Red River Basin]

Species	Counties	Action Alternatives	Predominant Habitat
Adder's-tongue fern (*Ophioglossum pusillum*)	Ransom, Richland	a,b,c,d,e,f,g	prairie swales
Alkaki sacaton (*Sporobolus airoides*)	Grand Forks	a,b,c,d,e,f,g	alkali seeps
American peregrine falcon (*Falco peregrinus anatum*)	Cass	a,b,c,d,e,g	cliffs along rivers and lakes
Bicknell's sunrose (*Helianthemum bicknellii*)	Ransom	c	open woods, prairies
Black ash (*Fraxinus nigra*)	Pembina	d	swampy or wet woods
Black-footed ferret (*Mustela nigripes*)	Burleigh	e	prairies
Blue cohosh (*Caulophyllum thalictroides*)	Barnes, Cass, Ransom, Richland	a,b,c,d,e,f,g	moist woods
Bog violet (*Viola conspersa*)	Grand Forks	a,b,c,d,e,f,g	moist woods, stream banks
Broad-winged skipper (*Poanes viator*)	Ransom, Richland	a,b,c,d,e,f,g	marshes, woods
Brook flatsedge (*Cyperus bipartitus*)	Ransom, Stutsman	c,e	streams
Buxbaum's sedge (*Carex buxbaumii*)	Barnes, Griggs, Steele, Stutsman	a,b,c,e,f	wet meadows, fens
Cutleaf watermilfoil (*Myriophyllum pinnatum*)	Stutsman	e	marshes, shores
Delicate sedge (*Carex leptalea*)	Pembina, Ransom, Richland	a,b,c,d,e,f,g	shrubby peatland fens, swampy woods and thickets
Dion skipper (*Euphyes dion*)	Ransom	c	marshes, woods
Dotted smartweed (*Polygonum punctatum*)	Grand Forks, Richland	a,b,c,d,e,f,g	swampy thickets, river banks, wet meadows
Downy hawthorn (*Crataegus mollis*)	Grand Forks, Ransom	a,b,c,d,e,f,g	open mesic woods
Dutchman's breeches (*Dicentra cucullaria*)	Sargent	c	woods

Species	Counties	Action Alternatives	Predominant Habitat
Dwarf spikerush (*Eleocharis parvula*)	Sargent	c	shores
Fisher (*Martes pennanti*)	Pembina	d	woods
Foxtail sedge (*Carex alopecoidea*)	Ransom, Richland	a,b,c,d,e,f,g	moist woods
Fringed gentian (*Gentianopsis crinita*)	Pembina	d	wet prairies, stream banks
Graceful sedge (*Carex gracillima*)	Pembina	d	moist swampy woods
Greater prairie chicken (*Tympanuchus cupido pinnatus*)	Ransom, Richland, Sargent	a,b,c,d,e,f,g	prairies
Greater redhorse (*Moxostoma valenciennesi*)	Cass, Ransom, Richland	a,b,c,d,e,f,g	rivers
Green keeled cottongrass (*Eriophorum viridicarinatum*)	Ransom	c	bogs, fens
Hair beakrush (*Rhynchospora capillacea*)	Stutsman, Wells	a,b,c,e	fens, seeps
Handsome sedge (*Carex formosa*)	Richland	a,b,c,d,e,f,g	moist woods
Hooked crowfoot (*Ranunculus recurvatus*)	Grand Forks	a,b,c,d,e,f,g	wooded ravines, swampy woods
Leathery grapefern (*Botrychium multifidum*)	Richland	a,b,c,d,e,f,g	wet meadows, woods
Ledge spike-moss (*Selaginella rupestris*)	Pembina	d	sandy soils, near oak woods
Lesser bladderwort (*Utricularia minor*)	Stutsman	e	fens, seeps
Lesser-panicled sedge (*Carex diandra*)	Grand Forks	a,b,c,d,e,f,g	swamps, meadows, shores
Loesel's twayblade (*Liparis loeselii*)	Kidder, Ransom, Stutsman	c,e	damp woods, prairie swales, fens
Low flatsedge (*Cyperus diandrus*)	Ransom	c	shores, stream margins
Marsh bellflower (*Campanula aparinoides*)	Ransom	c	wetland thickets, peat seeps
Marsh horsetail (*Equisetum palustre*)	Ransom, Richland	a,b,c,d,e,f,g	thickets, swampy woods, stream banks
Meadow horsetail (*Equisetum pratense*)	Pembina, Ransom	c,d	boggy woods, shady river banks and shores

Species	Counties	Action Alternatives	Predominant Habitat
Meadow onion (*Allium canadense*)	Sargent	c	prairies, open woods
Moonwort (*Botrychium minganese*)	Ransom	c	woods, meadows
Mulberry wing (*Poanes massasoit*)	Ransom, Richland	a,b,c,d,e,f,g	marshes, woods
Nodding ladies'-tresses (*Spiranthes cernua*)	Richland, Stutsman	a,b,c,d,e,f,g	fens, prairies
Oakfern (*Gymnocarpium dryopteris*)	Ransom	c	wooded slopes
Prairie skink (*Eumeces septentrionalis*)	Barnes, Ransom, Richland, Sargent	a,b,c,d,e,f,g	sand dunes, grasslands
Pugnose shiner (*Notropis anogenus*)	Grand Forks, Stutsman	a,b,c,d,e,f,g	lentic waters
Purple cinquefoil (*Potentilla palustris*)	Grand Forks	a,b,c,d,e,f,g	fens, wet meadows, bogs
Purple sandgrass (*Triplasis purpurpea*)	Ransom, Richland	a,b,c,d,e,f,g	prairies
Regal fritillary (*Speyeria idalia*)	Burleigh, Cass, Ransom, Richland, Sargent	a,b,c,d,e,f,g	prairies
Rocky mountain iris (*Iris missouriensis*)	Burleigh, Kidder, Stutsman	e	mesic prairies
Richardson's sedge (*Carex richardsonii*)	Cass, Richland	a,b,c,d,e,f,g	prairies
Sensitive fern (*Onoclea sensibilis*)	Pembina, Ransom, Richland	a,b,c,d,e,f,g	wetland thickets, fen peatlands, damp woods
Sessile-leaved bellwort (*Uvularia sessilifolia*)	Pembina	d	woods
Showy lady's-slipper (*Cypripedium reginae*)	Pembina, Ransom, Richland	a,b,c,d,e,f,g	swampy woods and thickets, fens
Sicklepod (*Arabis canadensis*)	Sargent	c	mesic woods
Slender cottongrass (*Eriophorum gracile*)	Ransom	c	fens
Slender pondweed (*Potamogeton filiformis*)	Barnes	c,e,f	lakes, ponds, streams
Small yellow lady's-slipper orchid (*Cypripedium parviflorum*)	Grand Forks, Pembina, Ransom, Sargent, Walsh	a,b,c,d,e,f,g	moist woods, fens, stream banks
Southern watermeal (*Wolffia columbiana*)	Pembina, Richland	a,b,c,d,e,f,g	aquatic
Spiny naiad (*Najas marina*)	Richland	a,b,c,d,e,f,g	alkaline lakes, ponds

Species	Counties	Action Alternatives	Predominant Habitat
Spring cress (*Cardamine bulbosa*)	Ransom	c	wet meadows and woods, springs
Swamp smartweed (*Polygonum hydropiperoides*)	Pembina	d	rooted in or near water
Upright pinweed (*Lechea stricta*)	Ransom, Richland	a,b,c,d,e,f,g	dry woods and prairies
Wahoo (*Euonymus atropurpureus*)	Cass, Ransom, Richland	a,b,c,d,e,f,g	woods, wood edges, river banks
Water arum (*Calla palustris*)	Pembina	d	marshes, swamps
Water-thread pondweed (*Potamogeton diversifolius*)	Stutsman	e	ponds, marshes
White lady's-slipper (*Cypripedium candidum*)	Cass, Foster, Grand Forks, Griggs, Ransom, Richland, Walsh	a,b,c,d,e,f,g	prairies, wet meadows
Wood horsetail (*Equisetum sylvaticum*)	Pembina	d	moist woods, seeps
Wooly beach-heather (*Hudsonia tomentosa*)	Ransom	c	prairies, dunes
Yellow monkeyflower (*Mimulus guttatus*)	Grand Forks	a,b,c,d,e,f,g	marshes, stream and lake shores
Yellow rail (*Coturnicops noveboracensis*)	Grand Forks, Sheridan, Stutsman	a,b,c,d,e,f,g	meadows, marshes
Zigzag goldenrod (*Solidago flexicaulis*)	Ransom, Sargent	c	woods

4.2.8 Invasive Species

Invasive species adversely effect biodiversity and are linked to lost revenue, property damage, and eradication expenses (Pimental et al. 2000). Their life history attributes (see USGS 2005a) enable invasive species to successfully outcompete native species for preferred habitats, which leads to altered communities and homogenization of landscapes (Figure 4-20). Invasive species are often particularly good at colonizing areas disturbed by human activities (e.g., roadsides, old fields). Newly created wet areas will also be utilized (Pyke and Havens 1999). Once established, invasive species may be difficult control or eradicate.

Figure 4-20. Purple loosestrife in bloom, an example of the homogenization of habitat by invasive species. Photo credit: Gary Fewless.

North Dakota has provisions to control the spread of invasive species (Schlueter 2005). The state's Game and Fish Department has developed management plans for aquatic nuisance plants and animals (Schlueter 2005). Water-associated plant species identified by the Department are Eurasian water-milfoil (Sheyenne River and Ransom County), curly-leaf pondweed (Missouri River), salt cedar/tamarisk (Missouri River and Richland County), and purple loosestrife (some eastern counties) (Lynn Schlueter, personal communication). Purple loosestrife is one of the most aggressive and widespread exotic plants in both North Dakota and Minnesota (Figure 4-21), and was introduced to the United States from Eurasia in the early

1800's (see USGS 2005a). It can spread at a rate of thousands of hectares per year and change wetland structure (Thompson et al. 1987). The common carp (widespread) and goldfish (occasionally sampled) are the aquatic nuisance animal species present in the state (Lynn Schlueter, personal communication). Zebra mussels have not yet been found in North Dakota, but could invade from nearby states such as Minnesota.

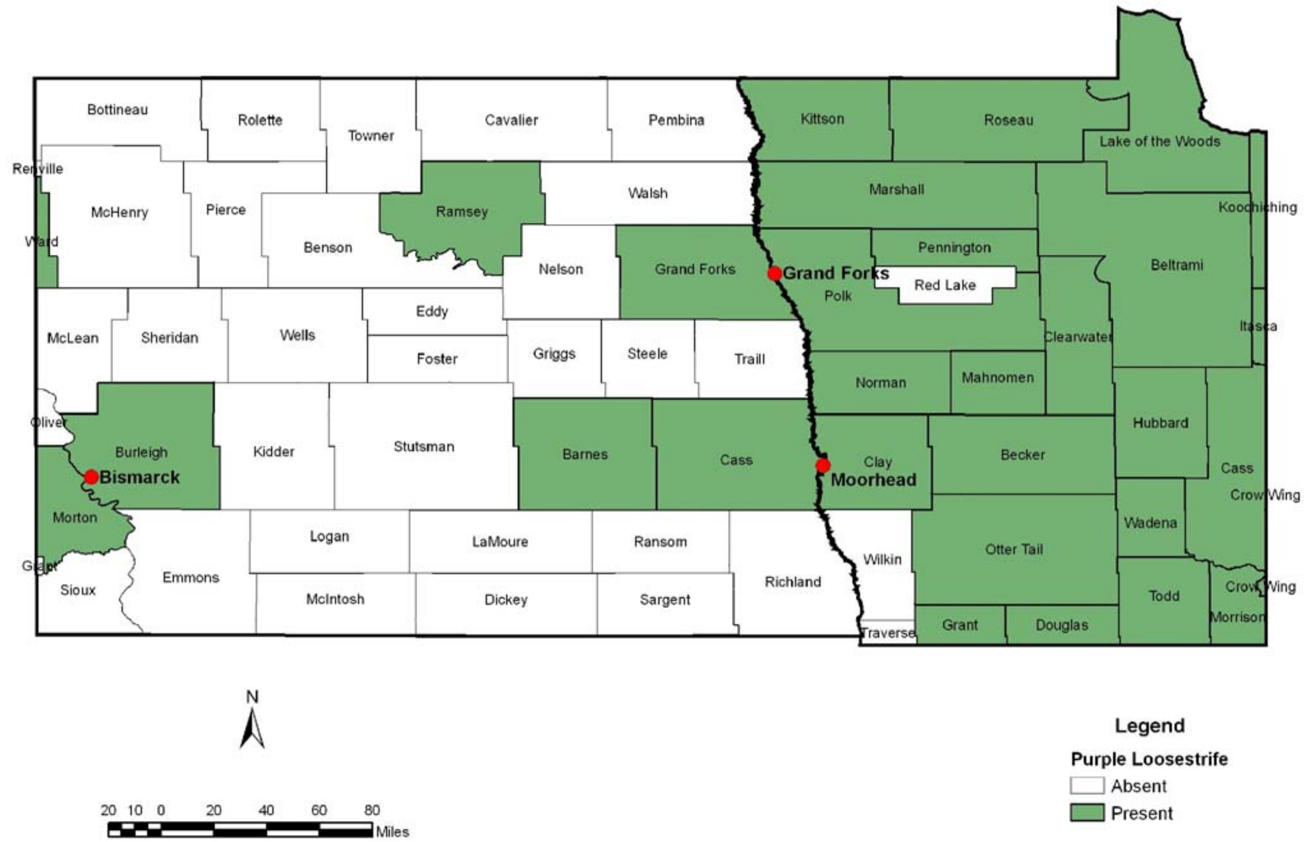


Figure 4-21. The presence/absence of purple loosestrife in North Dakota and Minnesota counties.

Minnesota has several pieces of legislation to control invasive species, and management plans exist for some individual species (Invasive Species Program 2006). Invasive aquatic plants managed by the state include Eurasian water-milfoil, purple loosestrife, curly-leaf pondweed, and flowering rush (Invasive Species Program 2006). Invasive aquatic animal species include common carp, zebra mussels, and mute swans (Invasive Species Program 2006). Of these, purple loosestrife (Figure 4-21), curly-leaf pondweed (Figure 4-22), and common carp (Figure 4-23) have been documented in counties crossed by proposed water pipeline routes. Zebra mussels have not been found in western Minnesota, but occur in the central part of the state as far west as Crow Wing County (Invasive Species Program 2006). Other invasive species that exist in the state are not actively managed. Asian carp are not known to be established in Minnesota, but are quickly expanding their distribution in the upper Mississippi River.

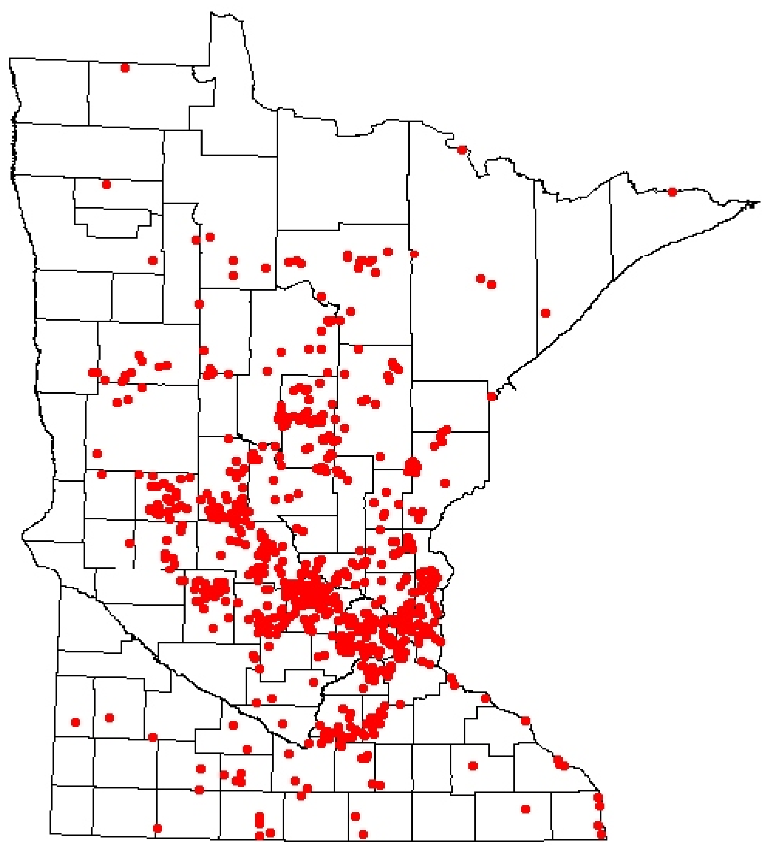


Figure 4-22. The geographic distribution of curly-leaf pondweed in Minnesota (reproduced from Figure 8 in Invasive Species Program 2006).

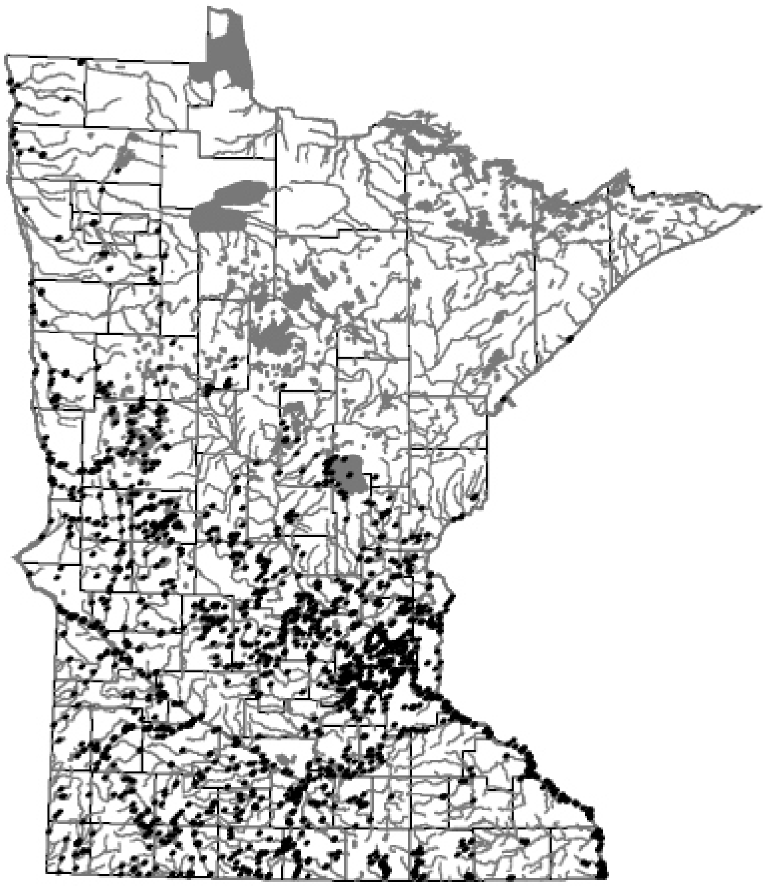


Figure 4-23. The geographic distribution of common carp in Minnesota (reproduced from Figure 23 in Invasive Species Program 2006).

Habitat changes potentially associated with pipeline burial and unintended releases of piped water include soil disturbance associated with construction and installation, and potential effects associated with unattended water loss through pipe leaks and breaks, e.g., altered hydroperiods for existing temporary water bodies. Collateral effects associated with interbasin water diversion may favor the spread and establishment of invasive species beyond their present distribution (Rachich and Reader 1999). For example, purple loosestrife seeds are dispersed by wind, water, and animals to other locations that have suitable attributes, and pipeline rights-of-way could become corridors for species invasions or expansion of existing distributions (Wilcox 1989).

4.3 Summary

Proposed Action Alternatives for the Red River Valley Water Supply Project involve the burial of pipeline through portions of eastern North Dakota and western Minnesota. Ecologically, the region is complex, having numerous “receptors” to serve as representative species or habitats critical to route selection, since that facet of project development affords resource managers countermeasures to offset potential adverse effects associated with infrastructure failures. For example, there are sensitive areas and associated flora and fauna scattered throughout the region that may better be avoided during the route selection process rather than accept the risk potentially associated with system failures unintentionally involving these habitats. Unintended releases of piped water, e.g., through water loss, will always occur in any pipeline, and reducing adverse collateral effects associated with these releases should be captured in system design, construction and installation, and long-term planning.

5.0 Habitat Equivalency Analysis for Sheyenne River and Lake Ashtabula

USGS (2005a) presents a consequence analysis of risks associated with biota transfer potentially linked to interbasin water diversions between the Upper Missouri River and Red River basins. The specific areas addressed in that analysis are the Red River from Fargo, North Dakota, to Lake Winnipeg, and Lake Winnipeg. A subsequent report (USGS, 2005b) extends that analysis to include the Lower and Upper Red Lakes, and the Red Lake River. This section further extends the analyses in USGS (2005a,b) to include the Sheyenne River and Lake Ashtabula. The Sheyenne River flows generally eastward and joins the Red River near Fargo, North Dakota (Figure 5-1). Lake Ashtabula is a man-made reservoir located on the Sheyenne River just north of Valley City, North Dakota.

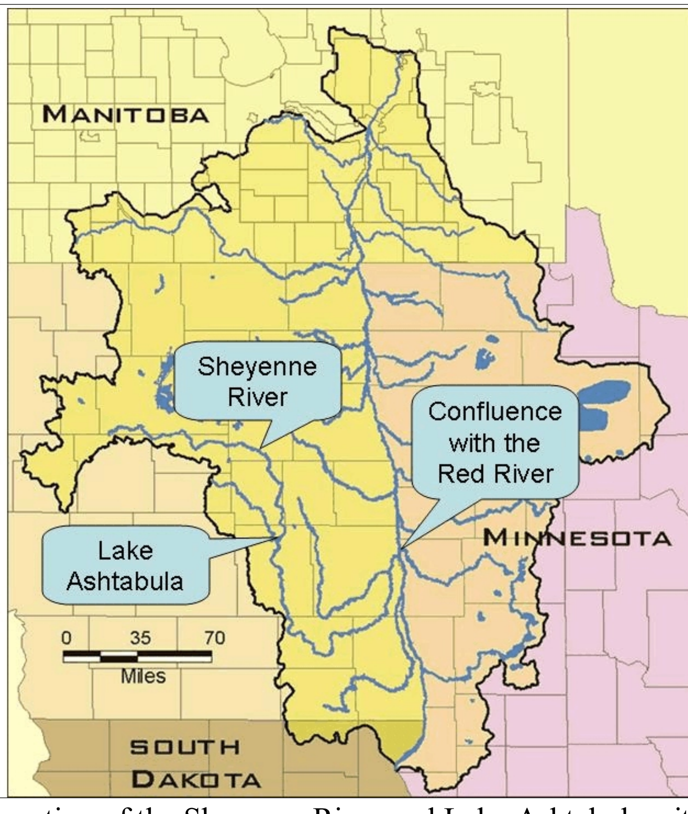


Figure 5-1. Location of the Sheyenne River and Lake Ashtabula within the Red River Basin

This section extends habitat equivalency analysis (HEA) previously employed by USGS (2005a,b) to rank the potential consequences for the Sheyenne River and Lake Ashtabula relative to those already estimated for the Red River, Lake Winnipeg, the Lower and Upper Red Lakes, and the Red Lake River. The results of this analysis indicate similar potential consequences for the Sheyenne River as for the Red and Red Lake Rivers, and significantly lower potential consequences for Lake Ashtabula than for Lake Winnipeg or the Lower and Upper Red Lakes. Given those results, the conclusion in USGS (2005a) that the majority of the potential consequences from risks of biological invasion would likely occur in Lake Winnipeg continues to hold.

Additionally, the HEA results indicate larger potential consequences under Missouri River Import to Red River Valley (MRIRRV) alternative than under the GDU Import to Sheyenne River (GDUISR) alternative. This outcome results primarily from the additional time invasive biota are assumed to require in order to traverse the Sheyenne River and reach the Red River under the GDUISR alternative. No additional time was assumed for invasive biota to reach the Red River under the MRIRRV alternative, since Missouri River water would be piped directly to the Red River Valley under that alternative. Therefore, discounting within the HEA model indicates higher potential lost services and higher potential consequences in present value terms for the MRIRRV alternative than for the GDUISR alternative. While the analysis of risks associated with each Action Alternative is consistent in each of the preceding reports, the reiteration of HEA in this focused analysis on the Sheyenne River captures the alternative-specific conditions that influence outcomes of the HEA, specifically those captured by time-dependent consequences related to release of Missouri River source waters to the Red River.

Section 6 of this report combines the HEA results for all water bodies (Red River, Lake Winnipeg, Lower and Upper Red Lakes, Red Lake River, Sheyenne River, and Lake Ashtabula) with the assessment of system failure risks reported earlier in this report (see Section 3). The analysis in Section 6 is intended to present a more comprehensive view of consequences resulting from the ecological and system failure risks potentially associated with the project.

5.1 Habitat Equivalency Analysis: Model Estimation

This analysis uses the same HEA model developed in USGS (2005a). The main differences between that analysis and the present analysis relate to the geographic distribution of potentially affected habitats, with a particular focus on Sheyenne River. The two alternatives addressed in this analysis, GDUISR and MRIRRV could potentially affect the Sheyenne River and Lake Ashtabula aquatic habitats with respect to biota transfers.[1] For purposes of this analysis, the Sheyenne River habitat is split between the 244.5 river-miles that extend north of Lake Ashtabula to its headwaters, and the 270.5 river-miles that extend south of Lake Ashtabula to its confluence with the Red River.[2] The 244.5 river-miles north of Lake Ashtabula are referred to in this analysis as the "Upper" Sheyenne River, and the 270.5 river-miles south of Lake Ashtabula are referred to as the "Lower" Sheyenne River. The Lake Ashtabula habitat is defined by its 27-mile length and 5,234-acre surface area (US Army Corps of Engineers 2006).

This analysis uses assumptions regarding biota dispersal methods and invasion rates that are similar to those used in USGS (2005a,b). The *progressive* dispersal method assumes a linear, geographically incremental advancement of a biological invasion. The particular progressive dispersal pattern to be analyzed depends on where imported water is discharged into the Sheyenne River and Lake Ashtabula habitats. Given the GDUISR alternative, a progressive dispersal would begin where imported water is discharged into the Sheyenne River, here assumed to be where the Upper Sheyenne River meets the northern shore of Lake Ashtabula. The progressive dispersal is then assumed to proceed north along the Upper Sheyenne River to its headwaters, and to proceed south along Lake Ashtabula to its southern shore. Finally, the progressive dispersal is assumed to proceed south along the Lower Sheyenne River (after it has traversed Lake Ashtabula) toward its confluence with the Red River.

The MRIRRV alternative would discharge imported water into the Sheyenne River and Lake Ashtabula habitats at a different location than the GDUISR alternative, and therefore would have a different progressive dispersal pattern. Given the MRIRRV alternative, a progressive dispersal would begin where transferred water is discharged into Lake Ashtabula, here assumed to be where the Lower Sheyenne River meets the southern shore of Lake Ashtabula. The progressive

[1] The frequency that Missouri River water could be discharged into the Sheyenne River/Lake Ashtabula system under the MRIRRV alternative has not been estimated. Therefore, to be conservative, this analysis assumes that Missouri River water could be discharged into the Sheyenne River/Lake Ashtabula system during any year under both the GDUISR and MRIRRV alternatives.

[2] The total length of the Sheyenne River is 542 miles (West Consultants, Inc. 2001). The Baldhill Dam gauging station is located 269.8 river-miles from the confluence of the Sheyenne River with the Red River and 0.7 river-miles south of Lake Ashtabula (US Geological Survey 2006). Lake Ashtabula is 27 miles in length (US Army Corps of Engineers 2006). Therefore, the length of the Sheyenne River south of Lake Ashtabula is 270.5 river-miles (269.8 river-miles to the Baldhill Dam gauging station plus 0.7 additional river-miles to Lake Ashtabula). The length of the Sheyenne River north of Lake Ashtabula is 244.5 river-miles (542 river-miles of total length minus the 270.5-mile length of the Sheyenne River south of Lake Ashtabula and minus the 27-mile length of Lake Ashtabula).

dispersal is then assumed to proceed south along the Lower Sheyenne River to its confluence with the Red River, and to proceed north along Lake Ashtabula to its northern shore. Finally, the progressive dispersal is assumed to proceed north along the Upper Sheyenne River (after it has traversed Lake Ashtabula) toward its headwaters.

The *jump* dispersal method is represented in this analysis by a simultaneous introduction of transferred biota into two geographically separate habitats. Given this method, under both the GDUISR and MRIRRV alternatives, transferred biota are assumed to be introduced simultaneously into the Lower Sheyenne River at the southern shore of Lake Ashtabula and into the Upper Sheyenne River at the northern shore of Lake Ashtabula. From those two points, the biological invader is assumed to proceed progressively north and south along respective habitats.

This analysis assumes that the rates of advancement of a biological invasion range between 1.55 and 15.5 miles per year (USGS 2005a). Those two rates were used to define *slow* and *fast* invasion speeds consistent with the consequence analyses in USGS (2005a,b). The invasion times indicated by those two speeds to traverse various water bodies given a progressive dispersal are shown in Table 5-1. After these habitats have been traversed by transferred biota, the resulting ecological service losses are assumed to continue into perpetuity.

Table 5-1. Invasion Times Given a Progressive Dispersal

		------Time Required to Traverse*------	
Water Body	**Length**	**Slow Invasion (1.55 miles/year)**	**Fast Invasion (15.5 miles/year)**
Upper Sheyenne River	244.5 miles	157 years	15 years
Lower Sheyenne River	270.5 miles	174 years	17 years
Lake Ashtabula	27 miles	17 years	1 year

* All invasion times were rounded down to the nearest whole year.

The only departure in this analysis from the times shown in Table 5-1 is for a jump dispersal in Lake Ashtabula. In that situation, the invasion effectively proceeds at twice the assumed speeds discussed above (2 x 1.55 = 3.1 miles per year for a slow invasion and 2 x 15.5 = 31 miles per year for a fast invasion), since the introduction of biota is assumed to occur simultaneously at both the southern and northern shores of Lake Ashtabula. Therefore, given a jump dispersal, a biological invasion is assumed to traverse Lake Ashtabula in 8 years for a slow invasion (27 miles divided by 3.1 miles per year), and in 0 years or instantaneously for a fast invasion (27 miles divided by 31 miles per year).[3]

This HEA quantifies the consequences of risk as the quantity of a certain provision of restoration that is required to offset an uncertain risk of successful biological invasion. The same assumptions made regarding the nature of this *offsetting restoration* in USGS (2005a,b) are used in this analysis as well. Specifically, it is assumed that offsetting restoration begins five years after the onset of successful invasion, and requires 20 years to become fully functional. These assumptions are made to allow sufficient time for planning, implementation, and mid-course corrections under adaptive management. Once offsetting restoration becomes fully functional, it is assumed to provide replacement ecological services that are equivalent to those potentially lost from biological invasion. Further, these replacement services are assumed to continue into perpetuity. Finally, a constant 3-percent annual discount rate is used in this analysis. This is the same discount rate used in USGS (2005a,b).

To support comparison across project reports (USGS 2005a,b), this HEA was also calculated for a single representative invasive organism given the progressive and jump dispersal methods and the slow and fast dispersal rates described above for the five different risk categories considered (very low, low, moderate, high, and very high risk). The results of those HEA calculations are presented in Table 5-2 for the GDUISR alternative and in Table 5-3 for the MRIRRV alternative. Detailed HEA calculations are presented in Appendices 2 and 3 for the GDUISR and MRIRRV alternatives, respectively.

[3] Invasion times were rounded down to the nearest whole year. Given that, a fast invasion is assumed to traverse Lake Ashtabula instantaneously given a jump dispersal.

Table 5-2. Offsetting Restoration for a Single Representative Invasive Organism Under the GDU Import to Sheyenne River Alternative

Lake Ashtabula - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes*	----Offsetting Restoration---- Slow Invasion (Acres)	Fast Invasion (Acres)
Very Low	1.00E-09	87.0%	0.00000632	0.00000792
Low	1.00E-06	7.6%	0.00623	0.00792
Moderate	1.00E-03	3.7%	6.32	7.92
High	1.00E-02	1.7%	63.2	79.2
Very High	1.00E+00	0.0%	6,320	7,920
Weighted Average			1.31	1.64

Lake Ashtabula - Jump Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes*	----Offsetting Restoration---- Slow Invasion (Acres)	Fast Invasion (Acres)
Very Low	1.00E-09	87.0%	0.00000716	0.00000816
Low	1.00E-06	7.6%	0.00716	0.00816
Moderate	1.00E-03	3.7%	7.16	8.16
High	1.00E-02	1.7%	71.6	81.6
Very High	1.00E+00	0.0%	7,160	8,160
Weighted Average			1.48	1.69

*The same probabilistic outcomes determined by USGS (2005a) were used in this analysis.

Table 5-2 *(Continued)*. Offsetting Restoration for a Single Representative Invasive Organism Under the GDU Import to Sheyenne River Alternative

Upper Sheyenne River - Progressive Dispersal

			----Offsetting Restoration----	
Risk Category	**Probability of Successful Invasion**	**Percent Outcomes***	**Slow Invasion (River-Miles)**	**Fast Invasion (River-Miles)**
Very Low	1.00E-09	87.0%	0.0000000801	0.000000303
Low	1.00E-06	7.6%	0.0000801	0.000303
Moderate	1.00E-03	3.7%	0.0801	0.303
High	1.00E-02	1.7%	0.801	3.03
Very High	1.00E+00	0.0%	80.1	303
Weighted Average			0.02	0.06

Lower Sheyenne River - Progressive Dispersal

			----Offsetting Restoration----	
Risk Category	**Probability of Successful Invasion**	**Percent Outcomes***	**Slow Invasion (River-Miles)**	**Fast Invasion (River-Miles)**
Very Low	1.00E-09	87.0%	0.0000000486	0.000000317
Low	1.00E-06	7.6%	0.0000486	0.000317
Moderate	1.00E-03	3.7%	0.0486	0.317
High	1.00E-02	1.7%	0.486	3.17
Very High	1.00E+00	0.0%	48.6	317
Weighted Average			0.01	0.07

Lower Sheyenne River - Jump Dispersal

			----Offsetting Restoration----	
Risk Category	**Probability of Successful Invasion**	**Percent Outcomes***	**Slow Invasion (River-Miles)**	**Fast Invasion (River-Miles)**
Very Low	1.00E-09	87.0%	0.0000000803	0.000000326
Low	1.00E-06	7.6%	0.0000803	0.000326
Moderate	1.00E-03	3.7%	0.0803	0.326
High	1.00E-02	1.7%	0.803	3.26
Very High	1.00E+00	0.0%	80.3	326
Weighted Average			0.02	0.07

*The same probabilistic outcomes determined by USGS (2005a) were used in this analysis.

Table 5-3. Offsetting Restoration for a Single Representative Invasive Organism Under the Missouri River Import to Red River Valley Alternative

Lake Ashtabula - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes*	----Offsetting Restoration---- Slow Invasion (Acres)	Fast Invasion (Acres)
Very Low	1.00E-09	87.0%	0.00000632	0.00000792
Low	1.00E-06	7.6%	0.00623	0.00792
Moderate	1.00E-03	3.7%	6.32	7.92
High	1.00E-02	1.7%	63.2	79.2
Very High	1.00E+00	0.0%	6,320	7,920
Weighted Average			1.31	1.64

Lake Ashtabula - Jump Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes*	----Offsetting Restoration---- Slow Invasion (Acres)	Fast Invasion (Acres)
Very Low	1.00E-09	87.0%	0.00000716	0.00000816
Low	1.00E-06	7.6%	0.00716	0.00816
Moderate	1.00E-03	3.7%	7.16	8.16
High	1.00E-02	1.7%	71.6	81.6
Very High	1.00E+00	0.0%	7,160	8,160
Weighted Average			1.48	1.69

*The same probabilistic outcomes determined by USGS (2005a) were used in this analysis.

Table 5-3 *(Continued)*. Offsetting Restoration for a Single Representative Invasive Organism Under the Missouri River Import to Red River Valley Alternative

Lower Sheyenne River - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes*	----Offsetting Restoration---- Slow Invasion (River-Miles)	Fast Invasion (River-Miles)
Very Low	1.00E-09	87.0%	0.0000000803	0.000000326
Low	1.00E-06	7.6%	0.0000803	0.000326
Moderate	1.00E-03	3.7%	0.0803	0.326
High	1.00E-02	1.7%	0.803	3.26
Very High	1.00E+00	0.0%	80.3	326
Weighted Average			0.02	0.07

Upper Sheyenne River - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes*	----Offsetting Restoration---- Slow Invasion (River-Miles)	Fast Invasion (River-Miles)
Very Low	1.00E-09	87.0%	0.0000000485	0.000000294
Low	1.00E-06	7.6%	0.0000485	0.000294
Moderate	1.00E-03	3.7%	0.0485	0.294
High	1.00E-02	1.7%	0.485	2.94
Very High	1.00E+00	0.0%	48.5	294
Weighted Average			0.01	0.06

Upper Sheyenne River - Jump Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes*	----Offsetting Restoration---- Slow Invasion (River-Miles)	Fast Invasion (River-Miles)
Very Low	1.00E-09	87.0%	0.0000000801	0.000000303
Low	1.00E-06	7.6%	0.0000801	0.000303
Moderate	1.00E-03	3.7%	0.0801	0.303
High	1.00E-02	1.7%	0.801	3.03
Very High	1.00E+00	0.0%	80.1	303
Weighted Average			0.02	0.06

*The same probabilistic outcomes determined by USGS (2005a) were used in this analysis.

The risks of successful biota transfers were not quantified specifically for the Sheyenne River or Lake Ashtabula. Rather, the same probabilistic outcomes determined by USGS (2005a, see Figure 1 in Section 4) were used in this analysis. These probabilistic outcomes were incorporated in Tables 5-2 and 5-3 by calculating the average of the HEA results for the different risk categories weighted by their respective percentage outcomes from USGS (2005a). These weighted averages were then aggregated to the 31 species of concern according to certain assumptions made regarding the number of jump dispersal events that might occur. These assumptions, described in Figure 5-2, are analogous to those made in USGS (2005a,b) for the Red River, Lake Winnipeg, Lower and Upper Red Lakes, and the Red Lake River

0 Jump - 31 Progressive: There are no jump dispersal events in this scenario. All 31 species of concern are assumed to begin their invasions at the point of discharge of Missouri River water into the Sheyenne River/Lake Ashtabula system. For the GDUISR alternative, invasions are assumed to begin at the northern shore of Lake Ashtabula and to progress north to the headwaters of the Sheyenne River - and south through Lake Ashtabula to the confluence with the Red River. For the MRIRRV alternative, invasions are assumed to begin at the southern shore of Lake Ashtabula and to progress south to the confluence with the Red River - and north through Lake Ashtabula to the headwaters of the Sheyenne River. In this analysis, this dispersal scenario yields the lowest levels of risk consequences in present value terms since it has the longest time horizon for any potential biological invasion to traverse the entire Sheyenne River/Lake Ashtabula system.

1 Jump - 30 Progressive: There is one jump dispersal event in this scenario. Under both the GDUISR and MRIRRV alternatives, one species of concern is assumed to begin its invasion simultaneously at the northern and southern shores of Lake Ashtabula. From those two points, the invasion is assumed to progress both north and south throughout the Sheyenne River/Lake Ashtabula system. The other 30 species of concern are assumed to follow the 0 Jump - 31 Progressive scenario described above.

10 Jump - 21 Progressive: There are ten jump dispersal events in this scenario. Under both the GDUISR and MRIRRV alternatives, ten species of concern are assumed to begin their invasions simultaneously at the northern and southern shores of Lake Ashtabula. From those two points, the invasions are assumed to progress both north and south throughout the Sheyenne River/Lake Ashtabula system. The other 21 species of concern are assumed to follow the 0 Jump - 31 Progressive scenario described above.

Figure 5-2. Dispersal Scenarios Included in the Analysis of the Sheyenne River and Lake Ashtabula

The aggregations to the 31 species of concern are presented in Table 5-4. These aggregations round to the same indicated levels of offsetting restoration for both the GDUISR and MRIRRV alternatives, and are not reported separately. These aggregations simply combine multiples of relevant weighted averages of the offsetting restoration levels for a single representative organism. For example, the aggregated offsetting restoration for Lake Ashtabula given a slow invasion and the 1 Jump - 30 Progressive dispersal scenario under the GDUISR alternative (40.8 acres in Table 5-4) was obtained by taking 1 times the offsetting restoration for a single representative invasive organism given a slow invasion and a jump dispersal (1.48 acres in Table 5-2) plus 30 times the offsetting restoration for a single representative invasive organism given a slow invasion and a progressive dispersal (1.31 acres in Table 5-2).

Table 5-4. Offsetting Restoration for 31 Biota of Concern Under Both the GDU Import to Sheyenne River and the Missouri River Import to Red River Valley Alternatives

	------Offsetting Restoration*------	
Dispersal Scenario	Sheyenne River (River-Miles)	Lake Ashtabula (Acres)
Slow Invasion		
0 Jump - 31 Progressive	0.9	40.6
1 Jump - 30 Progressive	0.9	40.8
10 Jump - 21 Progressive	1.0	42.3
Fast Invasion		
0 Jump - 31 Progressive	4.0	50.8
1 Jump - 30 Progressive	4.0	50.9
10 Jump - 21 Progressive	4.0	51.3

*Multiples of the weighted averages of the respective offsetting restoration levels for a single representative invasive organism (Tables 5-2 and 5-3), combined according to the dispersal scenarios (Figure 5-2).

As noted in USGS (2005a), the HEA results presented above assume the feasibility and availability of appropriate restoration measures. While the validity of that assumption is not clear at this time, these HEA results are useful in comparing the relative consequences associated with the Sheyenne River and Lake Ashtabula to those estimated for the Red River and Lake Winnipeg (USGS 2005a), and the Lower and Upper Red Lakes and the Red Lake River (USGS, 2005b). This comparison is presented in Tables 5-5 and 5-6 for all 31 biota of concern under the GDUISR alternative for the rivers and lakes, respectively. Tables 5-7 and 5-8 present that same comparison for the MRIRRV alternative.

For the GDUISR alternative, the HEA results previously reported by USGS (2005a,b) for the Red River, Lake Winnipeg, Red Lake River, and Lower and Upper Red Lakes were adjusted for the time assumed for biota invasions to reach those water bodies from the point where Missouri River water would be discharged into the Sheyenne River (above Lake Ashtabula).[4] Those adjustments were necessary in order to represent the HEA results for all water bodies on a comparable basis. No such adjustments were made to the HEA results for the MRIRRV alternative since Missouri River water under that alternative could be discharged directly into the Red River Valley and Lake Ashtabula potentially in the same year, without the biota invasion delays anticipated for the GDUISR alternative.

Table 5-5. Offsetting Restoration for 31 Biota of Concern: Comparison of the Red, Red Lake, and Sheyenne Rivers Under the GDU Import to Sheyenne River Alternative

	---------------Offsetting Restoration---------------		
Dispersal Scenario	Red River[a] (River-Miles)	Red Lake River[b] (River-Miles)	Sheyenne River[c] (River-Miles)
	Slow Invasion		
0 Jump - 31 Progressive	0.0	0.0	0.9
1 Jump - 30 Progressive	0.0	0.0	0.9
10 Jump - 21 Progressive	0.0	0.0	1.0
	Fast Invasion		
0 Jump - 31 Progressive	1.9	0.6	4.0
1 Jump - 30 Progressive	1.9	0.6	4.0
10 Jump - 21 Progressive	1.9	0.6	4.0

[a] HEA results from Table 2 in Section 5.3 of USGS (2005a) were adjusted for the time assumed for biota invasions to reach the Red River from the point where Missouri River water would be discharged into the Sheyenne River.
[b] HEA results from Table 7 in Section 3.1 of USGS (2005b) were adjusted for the time assumed for biota invasions to reach the Red Lake River from the point where Missouri River water would be discharged into the Sheyenne River.
[c] From Table 5-4 of this report

[4] The adjustment involves shifting the time path of lost services in the HEA forward by the number of years assumed for invasive biota to reach the affected water body from the point where Missouri River water would be discharged into the Sheyenne River. That time shift depends on the invasion speed (fast or slow) and dispersal scenario (jump or progressive) assumed for the Sheyenne River and Lake Ashtabula.

Table 5-6. Offsetting Restoration for 31 Biota of Concern: Comparison of Lake Winnipeg, Lower and Upper Red Lakes, and Lake Ashtabula Under the GDU Import to Sheyenne River Alternative

	---------------Offsetting Restoration---------------		
Dispersal Scenario	Lake Winnipeg[a] (Acres)	Lower and Upper Red Lakes[b] (Acres)	Lake Ashtabula[c] (Acres)
Slow Invasion			
0 Jump - 31 Progressive	0.0	0.0	40.6
1 Jump - 30 Progressive	1.3	0.2	40.8
10 Jump - 21 Progressive	15.3	2.9	42.3
Fast Invasion			
0 Jump - 31 Progressive	11,362.4	776.9	50.8
1 Jump - 30 Progressive	11,868.2	800.2	50.9
10 Jump - 21 Progressive	16,468.5	1,013.5	51.3

[a] HEA results from Table 2 in Section 5.3 of USGS (2005a) were adjusted for the time assumed for biota invasions to reach Lake Winnipeg from the point where Missouri River water would be discharged into the Sheyenne River.
[b] HEA results from Table 7 in Section 3.1 of USGS (2005b) were adjusted for the time assumed for biota invasions to reach the Lower and Upper Red Lakes from the point where Missouri River water would be discharged into the Sheyenne River.
[c] From Table 5-4 of this report

Table 5-7. Offsetting Restoration for 31 Biota of Concern: Comparison of the Red, Red Lake, and Sheyenne Rivers Under the Missouri River Import to Red River Valley Alternative

	---------------Offsetting Restoration---------------		
Dispersal Scenario	**Red River[a] (River-Miles)**	**Red Lake River[b] (River-Miles)**	**Sheyenne River[c] (River-Miles)**
	Slow Invasion		
0 Jump - 31 Progressive	0.6	0.0	0.9
1 Jump - 30 Progressive	0.6	0.0	0.9
10 Jump - 21 Progressive	0.6	0.0	1.0
	Fast Invasion		
0 Jump - 31 Progressive	3.1	1.2	4.0
1 Jump - 30 Progressive	3.1	1.2	4.0
10 Jump - 21 Progressive	3.1	1.2	4.0

[a] From Table 2 in Section 5.3 of USGS (2005a)
[b] From Table 7 in Section 3.1 of USGS (2005b)
[c] From Table 5-4 of this report

Table 5-8. Offsetting Restoration for 31 Biota of Concern: Comparison of Lake Winnipeg, Lower and Upper Red Lakes, and Lake Ashtabula Under the Missouri River Import to Red River Valley Alternative

	---------------Offsetting Restoration---------------		
Dispersal Scenario	**Lake Winnipeg[a] (Acres)**	**Lower and Upper Red Lakes[b] (Acres)**	**Lake Ashtabula[c] (Acres)**
	Slow Invasion		
0 Jump - 31 Progressive	1.9	2.8	40.6
1 Jump - 30 Progressive	360.0	70.4	40.8
10 Jump - 21 Progressive	3,583.7	679.0	42.3
	Fast Invasion		
0 Jump - 31 Progressive	19,322.3	1,316.0	50.8
1 Jump - 30 Progressive	20,165.1	1,354.9	50.9
10 Jump - 21 Progressive	27,750.3	1,705.3	51.3

[a] From Table 2 in Section 5.3 of USGS (2005a)
[b] From Table 7 in Section 3.1 of USGS (2005b)
[c] From Table 5-4 of this report

Tables 5-5 and 5-7 indicate similar potential consequences for the Sheyenne River as for the Red and Red Lake Rivers (within an order of magnitude). However, Tables 5-6 and 5-8 indicate significantly lower potential consequences for Lake Ashtabula than for Lake Winnipeg or the Lower and Upper Red Lakes (up to three orders of magnitude when compared to Lake Winnipeg).

Additionally, Tables 5-5 through 5-8 indicate larger potential consequences under the MRIRRV alternative than under the GDUISR alternative. For example, given a fast invasion and the 1 Jump - 30 Progressive dispersal scenario Lake Winnipeg would require 20,165 acres of offsetting restoration under the MRIRRV alternative, but only 11,868 acres under the GDUISR alternative. Those differences range from relatively minor (within one order of magnitude) to significant (up to two orders of magnitude) for the various water bodies. That result is primarily due to the additional time invasive biota are assumed to require to traverse the Sheyenne River and reach the Red River Valley under the GDUISR alternative.[5] Since water is piped directly to the Red River Valley under the MRIRRV alternative, it was assumed that Missouri River water could be discharged directly into the Red River Valley and Lake Ashtabula potentially in the same year, without the biota invasion delays anticipated for the GDUISR alternative. Therefore, discounting within the HEA model indicates higher potential lost services and potential consequences in present value terms for the MRIRRV alternative than for the GDUISR alternative.

5.2 Conclusions

This analysis extends the consequence analyses of USGS (2005a,b) to include the Sheyenne River and Lake Ashtabula. This analysis employs the same habitat equivalency analysis model, biota dispersal methods and invasion rates, percent outcomes for the probability of successful invasion, assumptions about offsetting restoration, and discount rate as used in USGS (2005a,b). The results indicate risk consequences ranging from 0.9 to 4.0 river-miles of offsetting restoration on the Sheyenne River and from 40.6 to 51.3 acres of offsetting restoration on Lake Ashtabula. As noted in USGS (2005a), these HEA results assume the feasibility and availability of appropriate restoration measures.

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[5] For example, a progressive dispersal is assumed to take 191 years in a slow invasion and 18 years in a fast invasion to reach the Red River from the point of Missouri River water discharge into the Sheyenne River under the GDUISR alternative. A jump dispersal is assumed to take 174 and 17 years for slow and fast invasions, respectively.

While the validity of that assumption is not clear, these results are useful in comparing the relative consequences associated with the various water bodies associated with the project. That comparison indicates similar potential consequences for the Sheyenne River as for the Red and Red Lake Rivers (within an order of magnitude), and significantly lower potential consequences for Lake Ashtabula than for Lake Winnipeg or the Lower and Upper Red Lakes (up to three orders of magnitude when compared to Lake Winnipeg). Given that comparison, the conclusion in USGS (2005a) that the majority of the potential consequences from risks of biological invasion would likely occur in Lake Winnipeg continues to hold.

Additionally, the HEA results indicate larger potential consequences under the MRIRRV alternative than under the GDUISR alternative. That result is primarily due to the additional time invasive biota are assumed to require in order to traverse the Sheyenne River and reach the Red River under the GDUISR alternative. No additional time was assumed for invasive biota to reach the Red River under the MRIRRV alternative since Missouri River water would be piped directly to the Red River Valley under that alternative. Therefore, discounting within the HEA model indicates higher potential lost services and higher potential consequences in present value terms for the MRIRRV alternative than for the GDUISR alternative.

6.0 Economic Consequences Incorporating Potential System Failures

Section 5 of this report describes the HEA for Sheyenne River and Lake Ashtabula, and compares the results of that analysis to similar analyses of the Red River and Lake Winnipeg (USGS 2005a), and the Lower and Upper Red Lakes and the Red Lake River (USGS 2005b). That comparison is presented in Tables 5-5 through 5-8. It is important to note that those results incorporate only the consideration of ecological risks. Since the various project alternatives include sophisticated systems to preclude the transmission of viable invasive biota to the Red River Basin (e.g., coagulation-flocculation-sedimentation, UV disinfection, membrane filtration, etc.), the effective ecological risks of biota transfers would be reduced below those addressed in the HEAs described above, along with the indicated levels of offsetting restoration. The degree to which risks and consequences are reduced depends on the efficacy and reliability of those systems. This section, then, incorporates the analysis of potential system failures in Section 3 with the HEA results in Section 5 to comprehensively address both ecological risks and the risks of system failure. Initially, however, to provide context for this integrated risk and consequence analysis, and the role that control system failure play in potentially mediating that risk, we briefly revisit the basis for our using HEA as a common tool across all USGS reports in the series.

6.1 Why HEA?

Throughout the series of three reports, HEA—habitat equivalency analysis—was selected as the analytical tool for consequence analysis, which assured consistency across the report series (USGS 2005a,b). A number of different economic analytical tools could be used to analyze potential consequences of biota transfer risks. These include methods that estimate the net economic values associated with these consequences, and regional economic impact analysis. A number of methods have been developed to estimate net economic values.[1] These methods generally rely on public surveys, which require significant investments in time and budget resources to design and implement.[2] These methods also involve highly technical economic behavioral modeling and statistical estimation techniques that can be difficult to explain to the public. While generally not requiring as many time and budget resources to implement, economic impact analysis can also involve public surveys and sophisticated modeling efforts.

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[1] See Freeman (1993) for a comprehensive survey of economic methods that are applicable to natural resources.
[2] If conducted by or for Federal agencies, surveys must also be approved by the Office of Management and Budget.

HEA, on the other hand, does not estimate economic values, but does incorporate their consideration in quantifying the consequences of management actions. HEA determines the size of ecological restoration projects that provide replacement services with an economic value at least as great as the economic value of the lost ecological services associated with the particular risk under consideration. That is, the size of the restoration project is determined to offset the economic value of lost ecological services. Therefore, the impacts are quantified as the size or cost of the required restoration project. The analytic inputs and results of HEA are directly associated with the potentially affected resources and their services. The results of HEA are easily understood by a broad range of interested parties.

This consequence analysis relies on HEA for two reasons. First, HEA is a relatively transparent economic approach, and describes consequences in terms of the amount of restoration that would be needed to address potential impacts. HEA is a relatively transparent economic approach. It describes consequences in terms of the amount of restoration that would be needed to address potential consequences. The analytic inputs and results of HEA are directly associated with the potentially affected ecological resources and their services. Because of that, the results of HEA are easily understood by a broad range of interested parties.

The second reason HEA was selected is because it is readily available in terms of the time and budget resources required for implementation. Unlike methods relying on public surveys, HEA can be conducted relatively quickly and at a modest cost. This feature has allowed the estimation of potential consequences over the broad geographical range of rivers and lakes potentially impacted by the project, providing a consistent method to estimate and compare the potential consequences of different components. Therefore, HEA was considered to be the most-effective approach for estimating and describing the consequences of risk throughout the entire assessment area.

6.2 Incorporation of Potential System Failures

Section 3 of this report concluded with the following categorical assessment of system failure rates. This assessment is organized according to three stages of project life: *early life* (within 1 year of project construction), *useful life* (20 years following early life), and *late life* (time after useful life).

- Early life system failure rate: 1 out of 10,000

- Useful life system failure rate: 1 out of 100,000
- Late life system failure rate: 1 out of 1,000

The way these system failure rates are incorporated into the consequence analyses depends on whether or not the ecological risks are independent of the system failure risks. At this point, there is no information to suggest that those two risks are not independent. Therefore, this analysis assumes independence and incorporates system failure risks by simply multiplying the consequence levels determined for ecological risks by the system failure rates presented above.

As the consequence levels in Tables 5-5 and 5-7, and the system failure rates listed above would suggest, the incorporation of system failure risks indicates 0.0 river-miles of offsetting restoration for the Red, Red Lake, and Sheyenne Rivers for all invasion speeds, all dispersal scenarios, all stages of project life, and both project alternatives analyzed. While offsetting restoration is not completely driven to zero for these habitats, the indicated magnitudes (all less than one-tenth of a river-mile) suggest insignificant consequences when the effects of these systems are considered.

Levels of offsetting restoration for Lake Winnipeg, Lower and Upper Red Lakes, and Lake Ashtabula indicated by the highest system failure rate (1 out of 1,000 for late life) for the GDU Import to Sheyenne River (GDUISR) and Missouri River Import to Red River Valley (MRIRRV) alternatives, respectively (Table 6-1 and Table 6-2). The levels of offsetting restoration indicated by the lower system failure rates (1 out of 10,000 for early life, and 1 out of 100,000 for useful life) would all be lower by one or two orders of magnitude. The highest level of offsetting restoration is 27.8 acres for Lake Winnipeg under the MRIRRV alternative, a level that occurs for the fast invasion speed and the 10 jump - 21 progressive dispersal scenario. Additionally, the following general observations can also be made:

- Levels of offsetting restoration and risk consequences are lower under the GDUISR alternative than they are under the MRIRRV alternative.
- Levels of offsetting restoration and risk consequences are higher for Lake Winnipeg than they are for the Lower and Upper Red Lakes or Lake Ashtabula.

Table 6-1. Offsetting Restoration for 31 Biota of Concern Incorporating Potential System Failures for Late Project Life: Comparison of Lake Winnipeg, Lower and Upper Red Lakes, and Lake Ashtabula Under the GDU Import to Sheyenne River Alternative

Dispersal Scenario	---------------Offsetting Restoration*--------------- Lake Winnipeg (Acres)	Lower and Upper Red Lakes (Acres)	Lake Ashtabula (Acres)
	Slow Invasion		
0 Jump - 31 Progressive	0.0	0.0	0.0
1 Jump - 30 Progressive	0.0	0.0	0.0
10 Jump - 21 Progressive	0.0	0.0	0.0
	Fast Invasion		
0 Jump - 31 Progressive	11.4	0.8	0.1
1 Jump - 30 Progressive	11.9	0.8	0.1
10 Jump - 21 Progressive	16.5	1.0	0.1

*Levels of offsetting restoration from Table 5-6 multiplied by the system failure rate for late project life (1 out of 1,000 or 0.001) and rounded to the nearest one-tenth acre.

Table 6-2. Offsetting Restoration for 31 Biota of Concern Incorporating Potential System Failures for Late Project Life: Comparison of Lake Winnipeg, Lower and Upper Red Lakes, and Lake Ashtabula Under the Missouri River Import to Red River Valley Alternative

Dispersal Scenario	---------------Offsetting Restoration*--------------- Lake Winnipeg[a] (Acres)	Lower and Upper Red Lakes[b] (Acres)	Lake Ashtabula[c] (Acres)
	Slow Invasion		
0 Jump - 31 Progressive	0.0	0.0	0.0
1 Jump - 30 Progressive	0.4	0.1	0.0
10 Jump - 21 Progressive	3.6	0.7	0.0
	Fast Invasion		
0 Jump - 31 Progressive	19.3	1.3	0.1
1 Jump - 30 Progressive	20.2	1.4	0.1
10 Jump - 21 Progressive	27.8	1.7	0.1

*Levels of offsetting restoration from Table 5-6 multiplied by the system failure rate for late project life (1 out of 1,000 or 0.001) and rounded to the nearest one-tenth acre.

6.2 Conclusions

Section 6 incorporates the analysis of potential system failures presented in Section 3 of this report with the HEA results reported in Section 5. The effect of that incorporation greatly reduces the indicated consequences of biota transfer risks. The main conclusions of this incorporation are:

- the incorporation of system failure risks indicates 0.0 river-miles of offsetting restoration for the Red, Red Lake, and Sheyenne Rivers for all invasion speeds, all dispersal scenarios, all stages of project life, and both project alternatives analyzed. This result indicates insignificant risk consequences for these rivers once the effects of biota control systems are accounted for, and

- for the lakes, the highest level of offsetting restoration and risk consequences occurs for Lake Winnipeg under the MRIRRV alternative (27.8 acres). That level occurs for the most severe scenario analyzed (fast invasion speed and the 10 jump - 21 progressive dispersal scenario).

In general, levels of offsetting restoration and risk consequences are lower under the GDUISR alternative than they are under the MRIRRV alternative, again reflecting the time-sensitive conveyance-aided dispersal realized under MRIRRV. Levels of offsetting restoration and risk consequences are higher for Lake Winnipeg than they are for the Lower and Upper Red Lakes or Lake Ashtabula.

7.0 Interpretative Setting, Characterization of Risks Associated with Infrastructural Failures, and Uncertainties

Section 7.1 summarizes earlier USGS reports (USGS 2005a,b) that lead to the current investigation, and Section 7.2 summarizes engineering and technological options being considered as part of Action Alternatives outlined in the DEIS (Reclamation 2005a). With this background provided, Section 7.3 summarizes technical findings related to infrastructural failures that might occur relative to Action Alternatives for interbasin water diversions outlined in the DEIS (Reclamation 2005a), while Section 7.4 provides an initial summary of uncertainties associated with this failure and consequence analysis relative to risk management decisions. In part, risk management practices may be better informed consequent to this series of technical support documents (this report plus earlier installments in the series [USGS 2005a,b]).

7.1 Background on USGS CERC's Technical Analysis and Informing Decisions for the Red River Valley Water Supply Project

This section will consider background on technical support completed by USGS (2005a,b) that led to this preliminary failure and consequence analysis. Under the auspices of the Dakota Water Resources Act (DWRA) of 2000, the Secretary of the Interior had directed Reclamation to conduct a comprehensive study of the water quality and quantity needs of the Red River Valley and the options for meeting those needs. As part of their response to that charge, Reclamation requested technical support from USGS/CERC for an evaluation of the risks and economic consequences of biota transfers potentially associated with interbasin water transfers that might occur between the Upper Missouri River and the Red River of the North (Red River) basins. CERC staff and their Department of the Interior (DOI) partners in the National Park Service (NPS) initiated a three-report series[1,2,3] focused on concerns regarding interbasin biota transfer.

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[1]Risk and Consequence Analysis Focused on Biota Transfers Potentially Associated with Surface Water Diversions Between the Missouri River and Red River Basins (2005a).

[2]Risk Reduction Captured by Water Supply Alternatives and Preliminary Analysis of Economic Consequences Associated with Biota Transfers Potentially Realized from Interbasin Water Diversion (2005b).

[3]Infrastructural Failures and their Associated Risks and Consequences Related to Biota Transfers Potentially Realized from Interbasin Water Diversion (2006; this report)

As part of the risk analysis process, staff from the Reclamation Dakota Area Office (DAO) and stakeholders helped focus technical support activity through a series of Technical Team and Cooperator meetings convened in North Dakota during the project period (September 9 and 10, 2002; March 27, 2003; October 28, 2003; August 8-11, 2004; July 5-6, 2005; August 10-11, 2005; May 16-17, 2006) and through comments received from stakeholders through Reclamation staff consequent to those meetings.

7.1.1 Biota transfer report. The Biota Transfer Report (BTR; USGS 2005a) was completed following guidance from National Research Council/National Academy of Sciences (NRC/NAS) and National Invasive Species Council (NISC; see http://www.invasivespeciesinfo.gov/; see also USGS 2005a), regulatory agencies (e.g., US EPA; http://www.epa.gov/owow/invasive_species/), and other governmental (http://www.anstaskforce.gov/ default.php; see also USGS 2005a) and nongovernmental organizations such as The Nature Conservancy (http://tncweeds.ucdavis.edu/; see also USGS 2005a) and awardees of Sea Grant program (http://nsgd.gso.uri.edu/haccp.html; see also USGS 2005a). USGS/CERC entered into an iterative risk-assessment process summarized in the BTR, then implemented the stepwise risk analysis process with the primary outcomes detailed in the problem formulation phase of the USGS technical support project (see USGS 2005a). Outcomes of problem formulation were focused on identifying biota of concern (Table 7-1) and related issues associated with interbasin biota transfers, pathways potentially linking Missouri River and Red River basins, and the potential confounding factors that might influence the interpretation of cause-effect relationships predicated on biota transfers, if these events did occur in the future. Tools applicable to the analysis of risks and economic consequences were also characterized in the report, and set the stage for their contribution to derivative reports developed following the initial investigation. Complementary to the risk analysis, HEA—habitat equivalency analysis—was applied to the analysis of economic consequences potentially associated with interbasin biota transfers. In the analysis of risks, data-mining techniques were applied to open literature searches initiated for compiling existing data and information on biota of concern identified during problem formulation. Potential pathways directly associated with engineered interbasin water diversions were considered as one of many competing pathways linked to human device(s) or natural events (i.e., those not linked to anthropogenic activities), which were captured through a series of nested fault-probability trees (FPTs). FPTs graphically illustrated the biota transfer process potentially captured by interbasin water diversions and competing pathways linked to anthropogenic or natural (not aided by human devices or activity) processes. Tools applied to the analysis of risks included categorical and spatiotemporal tools employing traditional dot maps to characterize current distributions of biota

Table 7-1. Biota of concern identified for analysis focused on biota transfers from Upper Missouri River basin to Red River basin.[4]

Microorganisms and Infectious Diseases Enteric redmouth Infectious hemtopoietic necrosis virus (IHNV) *Escherichia coli* (various serotypes)* *Legionella* spp.* *Salmonella* spp. (including, but not limited, to *S. typhi, S. typhmurium,* other *Salmonella* serotypes, and other waterborne infectious diseases)*	**Aquatic invertebrates: Mollusks** Zebra mussel (*Dreissena polymorpha*) Asian clam (*Corbicula fluminea*) New Zealand mudsnail (*Potamopyrgus antipodarum*)
Protozoa and Myxozoa *Myxosoma cerebralis (Myxobolus cerebralis)* *Polypodium hydriforme* *Cryptosporidium parvum** *Giardia lamblia**	**Aquatic invertebrates: Crustaceans** Spiny water flea (*Bythotrephes cederstroemi*)
Cyanobacteria *Anabaena flos-aquae** *Microcystis aeruginosa** *Aphanizomenon flos-aquae**	**Aquatic vertebrates: Fishes** Gizzard shad (*Dorosoma cepedianum*) Rainbow smelt (*Osmerus mordax*) Paddlefish (*Polyodon spathula*) “Asian carp” Pallid sturgeon (*Scaphirhynchus albus*) Utah chub (*Gila atraria*) Zander (*Sander* [*Stizostedion*] *lucioperca*)
Vascular plants Hydrilla (*Hydrilla verticillata*) Eurasian water-milfoil (*Myriophyllum spicatum*) Water hyacinth (*Eichhornia crassipes*) Purple loosestrife (*Lythrum salicaria*) Salt cedar (*Tamarix* spp.; at least eight species have been listed as introduced into the U.S. and Canada)	**Invasive biota associated with sludge disposal and indirect pathways associated with interbasin water transfers, including:** Potential transfer of plant and disease organisms (plant, wildlife, and human) Potential transfer of genetically manipulated organisms Potential biota transfers derived from sludge disposal

† Composite grouping of species of carp originally entering North America from source areas in Asia; species include bighead carp (*Hypophthalmichthys* [*Aristichthys*] *nobilis*), silver carp (*Hypophthalmichthys molitrix*), and black carp (*Mylopharyngodon piceus*).

[4] Reclamation and Technical Team acknowledged the potential for interbasin water diversions to influence existing local populations in Missouri River and Red River basins. Species that currently occupy both basins were included on the list of biota of concern, since their potential interbasin water transfer may have adverse impact on fish and wildlife or human health.

of concern, and genetic algorithms focused on ecological-niche models to project potential distributions for biota of concern when data were sufficient.

The analysis of risks associated with potential biota transfers yielded multiple, complimentary outcomes stemming from the range of analytical tools applied to the evaluation of risks. Outcomes of the analysis of risks resulted from qualitative evaluations, largely based on narrative analyses dependent upon existing information on past and current distributions and life-history attributes potentially associated with future species incursions that might result in successful invasions or shifts in metapopulations. Quantitative evaluations based on categorical analysis considered life-history attributes and assigned numerical scores to each biota of concern, yielding a priority list of species likely to be problematic, if biota transfers occurred in the future. Outcomes of categorical analysis suggested that potential transfers of species already occurring in both Missouri River and Red River basins may occur in the future, since existing multiple competing pathways may link these basins regardless of whether designed water diversions are realized. Whether transfers of species already occurring in both basins would be associated with a measurable shift in metapopulations is unclear, given the relatively sparse data available for the analysis. While georeferenced distribution data were not sufficient for characterizing potential species distributions for all biota of concern, when sufficient data were available, spatiotemporal analysis considered biota transfers and prediction of species distributions through an ecological-niche based model algorithm. Illustrative projections of potential distributions for representative aquatic nuisance species (such as Zebra mussel, New Zealand mudsnail) and riparian plants (such as tamarisk) were incorporated into the quantitative analysis as available and suggested that some biota of concern may become invasive in the future, although these species invasions are not uniquely linked to interbasin water diversion, because of multiple pathways available for incursion.

Categorical and quantitative estimates of risk were developed in BTR and were characterized with respect to their attendant uncertainties. A narrative analysis of pathways and their potential risk derivatives was also considered, with a particular focus on biota of concern lacking data sufficient to more quantitative estimates of risks. Overall, risks of biota transfers varied across representative species of concern and followed a priority risk ranking as

Fishes << Aquatic invertebrates ≤ Aquatic and terrestrial-wetland plants < Waterborne disease agents ≤ Cyanobacteria

suggesting interbasin transfers of fishes would be least likely to occur; hence, risks would be very low. In contrast, transfers of waterborne disease agents and cyanobacteria (or their toxins) would be associated with greater risks, particularly if control systems were not incorporated into water diversion processes and infrastructure.

Outcomes of simulation studies suggested that greatest risk reduction would be achieved through a water transfer mediated in the presence of a control system characterized by treatment of intake water at the source and transmission via closed conveyance from Missouri River basin to Red River basin. Results of the simulation study suggested that risks of biota transfers under such a controlled, closed-conveyance scenario would range from low to very low (10^{-6} to 10^{-9} and less than 10^{-9}, respectively). The range of probabilities in the latter, very-low risk category would reach much lower levels in those scenarios where stochasticity in the biota transfer process was fully captured. Low probability-high consequence events likely remain, even under the most controlled engineering practice implemented for an interbasin water transfer or under a no-action alternative. Risks were greatest when interbasin water diversions were envisioned as being implemented via open conveyance and only slightly reduced if untreated waters were piped from exporting to importing basin. Greatest risk reduction was achieved when source waters were treated (e.g., using combined control technologies such as conventional water treatment and pressure-driven membrane filtration) within the exporting basin then transferred via closed conveyance (e.g., piped transfer) to importing basin.

BTR also included economic analyses that estimated the potential consequences associated with interbasin water transfers between the Upper Missouri River and Red River basins. Two economic approaches were used to estimate these consequences. HEA was used to estimate consequences throughout the assessment area including the Red River and Lake Winnipeg. That analysis indicated risk consequences ranging from 0.6 to 3.1 river-miles of offsetting restoration on the Red River and from 1.9 to 27,750 acres of offsetting restoration on Lake Winnipeg. While those results suggest potentially significant consequences for Lake Winnipeg, their interpretation depends on the feasibility and availability of appropriate restoration measures.

Since the feasibility and availability of those restoration measures is not clear at this time, a second economic approach was used to focus the consequence analysis on Lake Winnipeg. Regional economic impact analysis was used to estimate the impacts on output (sales revenue) and employment in the Lake Winnipeg commercial fishery. The invasion scenarios with the largest consequences (slow and fast invasions given a jump dispersal event) indicated a total expected present value between $33,000 and $136,000 in direct and indirect output impacts for all

Canadian provinces. All other invasion scenarios indicated smaller output impacts. Expected employment impacts in the very high-risk category (i.e., certainty) reach 331 full-time equivalent (FTE) jobs. The average expected employment impacts weighted by the percent outcomes of respective risk categories is 0 FTE for all invasion scenarios.

Three conclusions were apparent, given the quantitative results from HEA and the regional economic impact analysis. First, the overall results were sensitive to the distribution of probabilistic outcomes from the risk characterization. Consequence levels for the individual risk categories vary substantially, and that variance reflects the different probabilities of successful invasion. A different distribution of probabilistic outcomes would change the weighted averages of the consequence levels. In this particular case, the weighted average consequences were heavily weighted toward the lowest risk category (87% of outcomes in the very low-risk category). A distribution more heavily weighted toward the higher-risk categories would yield substantially higher-weighted averages of consequences.

Second, the speed of invasion significantly affects the quantitative results. As many as four orders of magnitude difference in offsetting restoration levels exist between the two invasions' speeds assumed in this analysis, and one order of magnitude difference is captured by output impacts. A much more detailed analysis would match individually estimated invasion speeds to respective organisms and then aggregate the indicated consequence levels over the species of concern. However, the information regarding species-specific invasion speeds was not available to conduct that level of analysis. Therefore, this analysis indicates not only the significance of this analytic factor but also the need for additional research in this area.

Third, the anticipated distribution of the method and number of dispersal events substantially affects the quantitative results. This analysis considered only a limited set of potential dispersal scenarios. No information was available to inform the distribution of these scenarios to include in the analysis. However, the limited number of potential dispersal scenarios analyzed here indicated as many as four orders of magnitude difference in offsetting restoration levels between them. Similar to the conclusion regarding the speed of biotic invasion, this analysis indicates a significant analytic factor and a need for further research. Overall, the technical findings of the BTR indicated that, if interbasin water diversion is realized, risks of biota transfers range from "highly likely to occur" to "highly unlikely to occur," depending on how the diversion is implemented. Economic consequences matched these technical findings focused on risk.

7.1.2 Supplemental Report on Risk Reduction and Proposed Alternatives. The second report in the series stemmed from a Reclamation request for a supplemental evaluation of risk reduction that may be realized by water supply and water treatment alternatives that had been proposed in their DEIS which was completed as part of their NEPA—National Environmental Policy Act—compliance process. Their DEIS discussed alternatives and options for meeting water needs of the Red River Valley through in-basin and interbasin water diversion sources. In parallel with this risk reduction evaluation, Reclamation also requested a preliminary analysis of economic consequences potentially realized at Upper and Lower Red Lakes and Red Lake River in Minnesota, if biota transfers occurred subsequent to an interbasin water diversion.

The Action Alternative providing greatest risk reduction as viewed through this preliminary analysis was the Garrison Diversion Unit (GDU) Water Supply Replacement Pipeline, although similarities in source water pretreatment and disinfection suggest acceptable risks may be addressed through control systems characterized by lesser risk reduction credit scores. It was also noted that the length and routing of pipeline in GDU, and location of water treatment operation would influence risks. Additionally, if costs had been included in this preliminary analysis, different priority rankings for Action Alternatives would likely have been observed. Although relatively short in duration, the open-water conveyance of treated waters via the Sheyenne River adversely effected the risk reduction credit score for the GDU Import to Sheyenne River alternative. Practically speaking, however, reservoir storage of treated waters in Lake Ashtabula may present similar risks with respect to biota transfers, which in part is reflected in the greatest risk reduction credits being realized by the GDU Water Supply Replacement Pipeline alternative, despite the conceptual design having the greatest length of pipeline. Each of these Action Alternatives may be equally foiled by stochastic events reflected in the biota transfer–species invasion process, yet the engineering options outlined by Reclamation (2005b,c) provide starting points for refined engineering analysis of risks and costs, or continued development of feasibility designs. If selection of an alternative is realized, or if some alternatives are eliminated from future consideration and others are moved forward in developing resource management plans, and regardless of the outcomes of potential future engineering analyses, a framework for evaluating the condition of water system components and prioritizing, e.g., pipe renewal projects and developing long-term monitoring programs must be part of the operation and maintenance of the water transmission and distribution network, if risks of biota transfer associated with interbasin water diversions and realized because of failures in the water transmission and distribution network are to be minimized.

Consequence Analysis for Red Lakes and Red Lake River. Beyond the economic consequence analysis incorporated into BTR, a supplemental analysis was undertaken for Red Lake River and the Lower and Upper Red Lakes using HEA. To assure comparative analysis between this effort and that previously completed for Lake Winnipeg and Red River, this analysis used the same HEA model, biota dispersal methods and invasion rates, assumptions about offsetting restoration, and discount rate as used in BTR (USGS 2005a). The results indicated risk consequences ranging from 0.0 to 1.2 river-miles of offsetting restoration on the Red Lake River and from 2.8 to 1,705 acres of offsetting restoration on the Lower and Upper Red Lakes. As noted in USGS (2005a), these HEA results assume the feasibility and availability of appropriate restoration measures. While the validity of that assumption is not clear, these results were useful in comparing the relative consequences associated with the Red Lake River and the Lower and Upper Red Lakes to those estimated for the Red River and Lake Winnipeg. That comparison indicates lower potential consequences for the Red Lake River than for the Red River, and lower potential consequences for the Lower and Upper Red Lakes than for Lake Winnipeg.

7.2 Failure in Control Systems and Risks of Biota Transfer

As noted in USGS (2005a,b), various technologies have been advanced to meet the water needs of a wide range of users, including an increased awareness of water's value as a resource beyond those needs directly related to human needs, e.g., for drinking water, municipal, and industrial applications. For water treatment targeted on a range of biota of concern—especially those potentially resulting from interbasin water transfers—a range of physical or chemical treatment techniques has historically helped limit occurrence of disease outbreaks and epidemics associated with drinking water in the US and Canada. These control technologies range from chemical and physicochemical treatments (e.g., chlorination and chloramination, UV disinfection) to physical barriers acting as filters (e.g., membrane technologies), each capable of reducing risks of biota transfers associated with interbasin water diversions (see Letterman 1999). These technologies may be used singly or in combination in control systems designed to meet user specifications. Regardless of configuration, however, the systems themselves present collateral risks that must be considered in any water resource management plan, e.g., chemical treatments such as chlorination may yield disinfection byproducts (DBPs) that result from interactions with naturally-occurring materials in the water and present health risks to end users (see, e.g., Percival et al 2004, Letterman 1999). Action Alternatives in the DEIS (Reclamation 2005a) included chlorination and UV treatment in conceptual designs along with conventional coagulation, flocculation, and sedimentation processes. Microfiltration was also included as a component in one Action Alternative (see Reclamation 2005a for detailed conceptual designs for each Action

Alternative). Given conceptual designs in the DEIS (Reclamation 2005a) and the panarchy process[5] associated with the NEPA process, this report should focus stakeholders on biota transfer issues through a technical analysis developed to inform the consensus-building process,[6] following prevailing risk assessment practice (see overview in USGS 2005a). The analysis in this current investigation was conditioned on conceptual designs provided by Reclamation pursuant to DWRA and comments from stakeholders (see USGS 2005a,b; see also Reclamation 2005a,b,c,d). Given the legislative and regulatory settings that affect the development of technical support efforts such as that undertaken here, the balance of Section 7.2 briefly identifies guidance that might resolve long-standing conflicts among participants in the panarchy process of NEPA, particularly as these relate to control systems designed to reduce risks associated with biota transfers potentially linked to interbasin water diversions.

7.2.1 Groundwater Disinfection. Some Action Alternatives include groundwater resources in their plans for meeting municipal and rural water needs of Red River Valley. According to EPA there are over 150,000 groundwater systems in the US (see http://www.epa.gov/safewater/ last accessed April, 2006). The "Groundwater Rule" is intended to address microbial contamination of groundwaters (see http://www.epa.gov/fedrgstr/EPA-WATER/2000/ May/Day-10/w10763.htm last accessed April, 2006). If the groundwater source is an unconfined aquifer, disinfection is required under the Groundwater Rule of the Safe Drinking Water Act. Although filtered by natural processes, ground water is often susceptible to microbial contamination, especially in rural systems, and source waters that may require disinfection as part of the treatment process. Increasingly, sources of drinking water dependent on groundwater have been found vulnerable to

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[5]Panarchy means an inclusive, universal system of governance in which all may participate meaningfully (see Sewell, J. and M. Salter, 1995, "Panarchy and Other Norms for Global Governance: Boutros-Ghali, Rosenau, and Beyond," Global Governance 3; see also Gunderson and Holling 2002).

[6]Consensus means overwhelming agreement and ideally reflects the product of a good-faith effort to meet the interests of all stakeholders. The key indicator of whether a consensus has been reached is that everyone or nearly everyone agrees with the group's resolution of issues following efforts to agree on outstanding interests. Interests are not the same as positions or demands. Demands and positions are what stakeholders say they must have, but interests are the underlying needs or reasons that explain why such positions are taken. Consensus strives for unanimity but may fail to achieve that goal of 100% support, in which case a group's resolution may not be meet everyone's satisfaction (ASTM 1998, also available at http://www.astm.org/cgi-bin/ SoftCart.exe/HISTORY/hist_index.html?E+mystore, last accessed May 23, 2006, see also http://web.mit.edu/publicdisputes/practice/ last accessed May 23, 2006)

microbial contamination. High levels of total coliform bacteria in ground water, including the indicator *E. coli* at levels that exceed regulatory benchmarks of the Total Coliform Rule, may indicate the presence of groundwater contamination with coliform bacteria and other infective agents (NRC 2004). Drinking water derived from groundwater sources has also been the source of nearly half of all waterborne disease outbreaks in the US, and with an increasing reliance on groundwater, inadequate disinfection of groundwater and untreated groundwater will continue to dominate as sources of waterborne disease outbreaks in the US (see CDC 2004 as cited in USGS 2005).

7.2.2 Surface Water Treatment Rule and beyond. Historically, disinfection of pathogenic microbes in drinking water has been largely successful due to chlorination. Yet recently, regulatory agencies have had to make trade offs between the benefits of chlorination and the risks associated with DBPs associated with chlorination processes. For example, the Surface Water Treatment Rule (SWTR) of 1989 mandated inactivation of *Giardia* cysts and enteric viruses and set treatment standards for trihalomethanes (THMs). Following SWTR guidance, water treatment plants were generally assured of adequate disinfection without exceeding DBP limits. Recent and on-going studies focused on evaluating human health effects associated with DBPs suggest that SWTR benchmarks for DBPs may present unacceptable risks. Hence, SWTR was amended in 1996 to lower DBP standards. In addition, an outbreak of cryptosporidiosis in Milwaukee in 1993 and other minor cryptosporidiosis outbreaks have lead regulators to establish a removal requirement for *Cryptosporidium* oöcysts in the 1998 Interim Enhanced Surface Water Treatment Rule (IESWTR). Additional requirements in the final ESWTR (as part of Long-Term 2 Enhanced Surface Water Treatment Rule, or LT2ESWTR) focus on a *Cryptosporidium* inactivation or removal. From a technical perspective, managing risks associated with *Cryptosporidium* and other organisms sharing similar life-history attributes will dominate discussions regarding proposed conveyance of waters from one basin to another, or from one sub-basin to another sub-basin.

Whether focus resolves on *Cryptosporidium* or other biota of comparable physical dimension, reliance on guidance from LT2ESWTR may be critical to extending guidance beyond the public health arena, particularly given stakeholder concerns related to disinfection-resistant biota that challenge water treatment efforts, i.e., chlorine treatment has not been demonstrated as being sufficient in treating *Cryptosporidium*, especially once the organisms have encysted. Other biota of concern (USGS 2005a) present challenges similar to that of *Cryptosporidium*, and experience garnered under LT2ESWTR may benefit discussions of risks associated with failures in control system envisioned to support interbasin water transfers. For example, other water treatment processes, e.g., adequate filtration, may provide protection from unknown biota when life history attributes such as those related to morphological traits, are shared by targeted biota in source waters. Also, under poor water quality conditions, a combination of disinfection technologies may be necessary to provide inactivation of *Cryptosporidium* and other protozoan, bacterial, and viral agents of waterborne disease (see, e.g., Percival et al 2004, White 1999, Letterman 1999, Schippers et al 2004).

7.2.3 Long-term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). In January, 2006 EPA published LT2ESWTR and Stage 2 Disinfectants and Disinfection By-Products Rule (DBPR). Since their initial proposals were aired in 2003, both rules have changed significantly with respect to requirements contained in each rule's final form. Requirements of drinking water systems of all sizes and types to comply with LT2ESWTR and DBPR occurred prior to states receiving primacy and the legal authority to enforce the rules. Hence, definition of rule's deadlines and guidance regarding rule implementation will initially be forthcoming from EPA until states assume enforcement responsibilities. While LT2ESWTR and DBPR do not directly pertain to the Action Alternatives, these rules may provide guidance applicable to reducing risks potentially associated with biota transfers.

As captured in the DEIS (Reclamation 2005), guidance related to DBPR may be marginal in helping to design a control system to support interbasin water transfers to meet water needs and demands of the Red River Valley in 2050. Stage 2 DBPR in its final form applies to water systems that treat their water with a disinfectant other than UV or deliver water that has been treated with a disinfectant other than UV. LT2ESWTR on the other hand applies to water distribution systems of all types and sizes that treat and distribute surface water or ground water under the direct influence of surface water. The rule's key provisions include:

- source water monitoring for *Cryptosporidium*, including a screening provision for small systems
- increased treatment requirements for systems with high *Cryptosporidium* source water results, and
- covering or treating uncovered finished water storage facilities.

While LT2ESWTR is directly responsive to public health issues, and in particular to issues related to *Cryptosporidium*, measures pursuant to LT2ESWTR may be applicable to addressing design specifications regarding biota transfer issues. For example, systems designed to use particle-size-based countermeasures for source waters containing *Cryptosporidium* would be one technical solution for reducing risks associated with biota identified as problematic in USGS (2005a).

7.2.4 Biota Treatment Incorporated Into Action Alternatives. For Action Alternatives proposed in the DEIS (Reclamation 2005a), disinfection or biota removal/inactivation occur as a two-step process wherein (1) particulate matter is removed by conventional water treatment methods to reduce turbidity in source waters and thus, reduce “habitat” for viruses and bacteria adsorbed to particulate material, then (2) pathogenic microorganisms are inactivated by physicochemical treatments such as UV disinfection, or removed through physical treatments (such as membrane filtration; see, e.g., Letterman 1999 for overview of water treatment process; see also Mallevialle et al 1996, Duranceau 2001, Schippers et al 2004 for discussions of membrane systems). In contemporary water supply systems, combined technologies are frequently applied to water treatment processes. As summarized in DEIS and supporting documents (Reclamation 2005a,b,c,d, Houston Engineering/Montgomery-Watson Harza Americas (HE/MWH) 2005), the Action Alternatives incorporate conventional pre-treatment—coagulation, flocculation, and sedimentation—as a common attribute of proposed biota treatment facilities, then use a physicochemical (UV disinfection) or physical (membrane) processes to reduce risks of biota transfers coincident with interbasin water diversions. A brief overview of each technology’s role in the proposed water transmission system follows.

Coagulation-Flocculation-Sedimentation. These pretreatment steps are typical of water treatment facilities, including an initial physical screening of source waters wherein physical debris (e.g., leaves, logs, sticks, litter such as plastic bottles), large invertebrates and fishes are removed from raw water drawn into the treatment plant. Following removal of physical debris and larger biota, raw water headed to the treatment facilities will pass through a series of conventional chemical treatments—coagulation-flocculation-sedimentation—intended to remove suspended solids and some impurities from raw waters. These three conventional treatment steps reduce or remove suspended solids which improves the appearance and taste of drinking water, reduces or removes some of microbiological contaminants that might be harmful to humans. The intended outcomes of pretreatment enhance performance in systems relying on UV disinfection by reducing total suspended solids (TSS). Depending on the engineering design, a “presedimentation” step may be included to remove settleable solids present in the water by gravity prior to conventional chemical treatment, if needed and determined effective. Dissolved chemical substances contributing to water hardness (e.g., iron, calcium, magnesium) are removed by lime softening in conjunction with conventional treatment and the addition of potassium permanganate during pretreatment. In general the conventional process does not removed dissolved solids.

Once raw water has passed through conventional treatment, various options are available to engineering design, including filtration and disinfection. Filtration options range from media filtration that relies on sand or other granular materials or through membrane filters of various porosities. All result in removal of solids and fine particles of various sizes, depending on the system's design. Disinfection options vary, depending on a water's specified end-use. In general, the disinfection process inactivates waterborne pathogens to assure safe consumption, e.g., for human populations, domestic animals, or application to other water uses (e.g., industrial applications, agriculture). Although not indicated in all water uses, water softening may also be incorporated into a system's design in order to remove minerals (primarily calcium and magnesium) that contribute to water hardness. Softening is accomplished either by adding lime in the conventional treatment process or by passing water through a nanofiltration membrane.

Chlorination, Chloramination, and Chlorine dioxide.[7] Disinfection in water treatment is required by the Surface Water Treatment Rule of 1990 and subsequent regulations (see, e.g., http://www.epa.gov/OGWDW/mdbp/ieswtr.html) which mandates effective disinfection through (1) filtration pre-treatment of source waters followed by (2) inactivation of organisms such as bacteria and viruses by disinfectants through, e.g., chlorination and chloramination, and (3) as applicable, treatment requirements for waterborne pathogens, e.g., *Cryptosporidium* spp. in addition to meet existing requirements for *G. lamblia* and viruses.

Water disinfection generally occurs as a two-step process wherein (1) particulate matter is removed by conventional filtration to reduce turbidity in source waters and thus, reduce "habitat" for viruses and bacteria adsorbed to particulate material, and then (2) pathogenic microorganisms are inactivated by chemical treatments (such as chlorination and chloramination), physicochemical treatments (such as UV disinfection), or removed through physical treatments (such as membrane filtration; see, e.g., Letterman 1999 for overview of water treatment process; see also Mallevialle et al 1996, Duranceau 2001, Schippers et al 2004 for discussions of membrane systems). More often than not, combined water treatment technologies are applied to the water disinfection process.

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[7]See USGS (2005a) for expanded discussion of chlorine, chloramine, and chlorine dioxide disinfection and technical references supporting that discussion.

Chlorination has been used as an agent for disinfection in the US over the past 100 years (see USGS 2005; see also Letterman 1999, and http://www.awwa.org/Advocacy/learn/info/HistoryofDrinkingWater.cfm last accessed December 8, 2004). Much of the process of chlorination relies on technology developed in the 1950's and 1960's (see White 1999 and earlier editions of this reference). Although the tools for chlorination have continued to be refined, few innovations have been made recently. Other disinfection technologies have been developed (e.g., ozonation, UV irradiation), but chlorine remains widely used as a disinfectant throughout the US because of its low cost, ability to form a residual, and its effectiveness at low concentrations. Overall, chlorine presents numerous advantages for disinfection, including the chemical's ease of application and residual presence in the distribution system, its effectiveness at low concentrations, and its relatively simple conversion to chloramines which also provide strong residual effects with limited disinfection by-products (DBPs). From an engineering cost perspective, chlorine is a relatively inexpensive disinfecting agent.

Despite these advantages, chlorine has "down side" characteristics that must be managed, if it is selected as a disinfection agent of choice. Chlorine reacts with organic materials in source waters, effectively reducing its concentration while creating trihalomethanes (THMs) and other DBPs compounds that may become health risks in drinking water distribution systems. More importantly from the perspective of its role as a disinfection chemical, chlorine provides poor disinfection for *Cryptosporidium* spp. and other microorganisms characterized by chlorine-resistant stages in their life history (e.g., spore formation; see USGS 2005, Appendix 3B). For target organisms such as *Cryptosporidium* spp., filtration provides an alternative disinfection method used singly or in conjunction with chlorination (see, e.g., Schippers et al 2004, Duranceau 2001, Mallevialle et al 1996).

Treatment with chloramine. Chloramines are the product of chloride reacting with ammonia, and some chloramines, particularly monochloramine, have also been used as disinfectants since the 1930's. Chloramine use in drinking water disinfections is an increasingly common standard practice among water utilities (see Haas 1999), in part, because of chlorine's disadvantages as a disinfectant. While chloramine is a weaker disinfectant than chlorine, it is more stable in water solutions under operating pH and the chemical's benefits as a disinfectant are available over longer periods of a system's operation, thereby providing a chlorine residual that promotes continued disinfection within the system.

Chloramine is used in water treatment primarily as a secondary disinfectant, since it helps maintain a disinfectant residual in the distribution system. Chloramine is also not as reactive as chlorine with organic material in water, thereby producing substantially lower concentrations of DBPs such as THMs and haloacetic acids (HAAs) which have associated adverse health effects at high levels. Because the chloramine residual is more stable and longer lasting than free chlorine, it provides better protection against bacterial regrowth in systems with large storage tanks and dead-end water mains and effectively controls formation of biofilms within the distribution system. Controlling biofilms reduces microbial habitat in distribution systems, which reduces concentrations of coliforms and other microorganisms, and helps reduce biofilm-induced corrosion of pipes. In addition to these technical advantages of chloramine, many drinking water utilities in the US have switched to chloramine as their disinfectant residual, since regulatory limits for THMs in drinking water have been lowered with promulgation of the Stage I Disinfection Byproducts Rule and subsequent administrative targets for lowering standards of DBPs (see EPA 2001a for a quick reference, or EPA 2001b).

Water Disinfection with chlorine dioxide. Chlorine dioxide (ClO_2) has found increased use in drinking water treatment, since it is as good as, or better as chlorine as a disinfectant (see White 1999). From a water treatment perspective, chlorine dioxide is a good oxidant, reducing iron, manganese, sulfur compounds, and odor-causing organic substances in raw waters. The chemical's increased use, however, stems in part from its use as a pre-oxidant, since chlorine dioxide does not as readily chlorinate organic compounds in source waters. In addition to the chemical's reduced reactivity with natural organic matter (NOM) or organic pollutants to form THMs or other chlorinated byproducts, chlorine dioxide has also found favor in water treatment, because ClO_2 will not oxidize bromide (Br^-) to bromate (BrO_3). Hypobromous acid (HOBr) can also form brominated DBPs in reactions with NOM. Regardless of the source of bromate, this constituent will be regulated at 0.010 mg/L by the Disinfectant-Disinfection By-Product (D-DBP) Rule, because of the chemical's health risks (EPA 2001c). As a disinfectant, ClO_2 is as good or better than chlorine for the inactivation of *Giardia* spp. and is better than either chlorine or chloramines for the inactivation of *Cryptosporidium* (see Letterman 1999, White 1999). While contact times will vary depending on system design, comparative contact times for chlorine, chloramines, and ClO_2 are summarized in Table 7-2 to illustrate the range of disinfection realized under various technologies (see Connell 1996, Haas 1999 and White 1999 for discussion).

In contrast to chlorine, chlorine dioxide does not react as readily with organic constituents in source waters; hence, chlorinated by-products such as THMs are reduced in the post-processing stream. For drinking water treatment, typical ClO_2 treatments have been targeted at less than 1.5 mg/L, given the maxmium daily residue load (MDRL) for finished-water concentrations of ClO_2 0.8 mg/L. By-products of chlorine dioxide include chlorite ion (ClO_2^-) and chlorate ion (ClO_3^-), which have been linked to potential adverse health effects, and subject to regulatory levels mandated by Stage 1 Disinfectant/Disinfection By-Products (D/DBP) Rule. Maximum contaminant level (MCL) for ClO_2^- is 1.0 mg/L, with no ClO_3^- MCL yet proposed (EPA 2001a). An summary table of representative contact times for these chlorine-based disinfectants has been compiled in Table 7-2.

Table 7-2. Examples of contact times (mg/L x minute) for various chlorine-based disinfectants (Connell 1996, Haas 1999, White 1999, Jacangelo et al. 2002).

Indicator	Chloramines	Chlorine	Chlorine Dioxide
Giardia lamblia 0.5 log inactivation pH 6-9, 5˚C	340-380	15-50	4.0-6.0
Viruses 2 log inactivation pH 6-9, 5˚C	825-900	4-7	5.0-6.0
Cryptosporidium parvum pH 7, 25˚C	7200 2 log inactivation	7200 1 log inactivation	78 1 log inactivation

Ultraviolet (UV) Disinfection of Drinking Water.[8] UV technologies have long been known to be effective for viruses and bacteria in drinking water and guidelines for the disinfection of viruses have been published (e.g., Alternative Disinfectants and Oxidants Guidance Manual, EPA 1999). However until relatively recently, UV was widely considered to be ineffective for encysted protozoa, since cyst membranes were thought relatively resistant to UV irradiation. Given *Giardia* cysts served as a "standard" for chlorine dose determinations, no reductions in chlorine usage were gained by using UV prior to 1998, based on technical literature available at the time. Hence, UV disinfection was not widely used for surface waters in the US and Canada. However, over the past 6 to 8 years studies using low to medium UV "doses" have demonstrated its effectiveness for inactivating *Cryptosporidium* and *Giardia* (see, e.g., Clancy et al 1998, 2000; Marshall et al 2003). In advance of new guidance and supporting technical support manuals for UV disinfection from EPA, water resource management agencies have begun to consider UV disinfection as an alternative for protozoa disinfection or to gain "CT credits" (disinfection

[8]Elaborated from USGS (2005a) and references cited therein.

credits) for UV for *Giardia*, so chlorine doses used for secondary disinfection can be lowered to meet DBP standards.

Use of UV radiation to disinfect water of waterborne pathogens relies on the germicidal properties of a narrow range of the UV spectrum (Figure 7-1). In sunlight, UV spectrum consists of discrete bands, with UVA and UVB (280–400nm) reaching earth's surface, while much of the UVC is filtered by interactions with ozone in the upper atmosphere. Shorter wavelength, higher energy UVC penetrates cells and causes DNA damage. As a disinfectant for water treatment, UV is germicidal, provided "dose" is sufficient (e.g., exposure duration long enough to yield target disinfection). UV wavelengths ranging from 240 to 280 nanometers (nm) deactivate microorganisms by damaging their DNA, and even if not killed, UV-exposed microorganisms do not replicate and thrive (see, e.g., McKey et al 2001, Jacangelo et al 2002), if DNA repair is not completed.

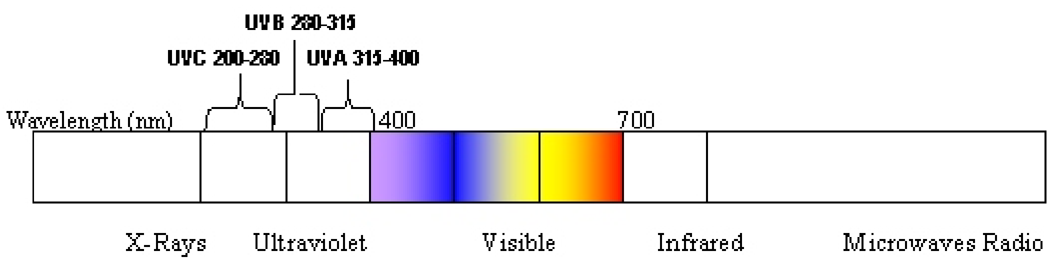

Figure 7-1. Electromagnetic spectrum illustrating ultraviolet (UV) relative to other forms of radiation.

UV dose measured in microwatt-seconds per square centimeter[9] is the product of UV intensity and exposure time, and exposures to attain, e.g., 90% deactivation of most bacteria and viruses range from 2,000 to 8,000 $\mu W\text{-}s/cm^2$. For disinfection targeted on *Giardia* spp., *Cryptosporidium* spp., and other large cysts and parasites, UV doses are an order of magnitude greater (approximately 60,000-80,000 $\mu W\text{-}s/cm^2$; see, e.g., McKey et al 2001, Jacangelo et al 2002). Most UV disinfection systems use low-pressure or medium-pressure mercury vapor lamps and expose water to UV by pumping the water around a sleeve within which the UV lamp is supported. Although not an essential component of UV treatment, systems may be coupled with a

[9]Power is measured in Watts, and Joules are units of energy. To convert Watts to Joules, 1 Watt = 1 Joule per second of power or 1 Watt-second = 1 Joule.

pre-filter to remove larger organisms that would otherwise pass through the UV system unaffected. The pre-filter also clarifies the water to improve light transmittance; therefore, UV dose is achieved throughout the entire water column. Proper handling and storage of UV-treated waters are a critical part of any UV treatment system, since UV treatment offers no residual disinfection. If bacteria are not killed as a result of UV exposure, organisms may undergo DNA repair (see, e.g., Mara and Horan 2003). The maximum absorption of DNA and maximum formation of photoproducts occurs between 260-265 nm. Unlike chlorination, UV treatment produces no known disinfection byproducts.

Water quality influences the effectiveness of UV disinfection, especially iron, water hardness, and TSS. Performance of UV disinfection systems is optimal when iron concentration, hardness, and TSS are low, and UV fluence is high. Fluence is the product of light intensity and exposure time as millijoules per square centimeter (mJ/cm^2), and is analogous to chlorine dose in water treatment even though UV relies on physical outcomes associated with DNA damage and chlorine disinfection results from a chemical process.

Although UV disinfection of source waters has increased in the past 10 to 12 years, concerns regarding performance of UV disinfection have been advanced (see Letterman 1999 and contributions therein as noted in Section 8). While UV is an effective tool for inactivating cryptosporidia and other pathogens resistant to chlorine, methods for assessing the efficiency of full-scale UV disinfection systems is based on the average dose that microorganisms will receive. This is then considered relative to the operating conditions of the system (e.g., hydraulic specifications) to estimate the fraction of microorganisms that might not receive a sufficient dose of UV radiation during passage through the disinfection system. The performance of a UV disinfection system depends on

- the rate at which water flows through the system,
- the intensity of the UV lamps, and
- the transmissivity of the water undergoing treatment.

which may be accounted for using biodosimetry (Marshall et al. 2003) or alternative methods for measuring the dose, or fluence, of a UV disinfection achieved in the system (see, e.g., Linden et al. 2005, Letterman 1999 and contributions therein as listed in Section 8). Microorganisms susceptible to UV disinfection will experience a range of UV exposures, depending on their path through the reactor chambers and the conditions present within the system. Biodosimetry relies on characterizing a reactor's "average dose," which does not fully specify a system's UV performance, given that the number of microorganisms receiving an inadequate dose or factors might be less than anticipated for the system as designed. In contrast to traditional biodosimetry, measurements of the distribution of fluence levels delivered in a UV disinfection system are taken, e.g., by employing fluorescent microspheres similar in size and density to microorganisms. Subsequent analysis of data derived from the system being evaluated relies on computational fluid dynamics and derivations of the distribution of UV intensity within a reactor which provides more accurate predictions of a UV system's fluence distribution (see, e.g., Malley et al. 2004, Mamane-Gravetz and Linden 2005).

Membrane filtration.[10] Membrane filtration technology has been increasingly applied to water treatment problems. The range of membrane technologies that provide efficient and safe water treatment alternatives are numerous (see Mallevialle et al. 1996; Duranceau 2001). Water treatment systems singly dependent on membrane filtration, or incorporating membrane technology within a multiple-treatment process, yield product waters of consistent quality that meets or exceeds water quality standards, especially with respect to disinfection (see, e.g., Schippers et al 2004). When operating as designed, membrane separation technology removes substances largely based on size and shape, with pore size and particle-size exclusion typically measured in nanometers (nm, or 10^{-9} meters), Angstroms (Å, or 10^{-10} meters), or molecular weight (MW, often times expressed as units, D for Daltons). A range of membranes have been developed with mass transfer properties and pore sizes such that ionic, molecular and organic substances measuring 1-1000 Å (MW between 100 and 500,000) are removed or rejected. As a "stand-alone" water treatment technology, membrane filtration is a physical process that may require little or no chemical treatment, depending on the choice of membrane device selected. Three general types are depicted in Figure 7-2, with microfiltration being identified as a "disinfection by removal" method of choice in the DEIS (Reclamation 2005).

Microfiltration is characterized as a solid-liquid separation process with a molecular weight cut off between between 0.1 µm and 10 µm (Figure 7-2). Microfiltration eliminates or reduces the passage of suspended particles, high-molecular weight lipids and fats, macromolecules, bacteria and protozoa (although *Cryptosporidium* spp. and *Giardia* spp. or their

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[10]See USGS (2005) for expanded discussion of membrane filtration and technical references supporting that discussion

cysts may not be removed completely; see Schippers et al. [2004]). It is frequently used for the production of drinking water and waste water treatment.

Ultrafiltration allows for filtration of smaller particles than microfiltration with a molecular weight cut off between between 0.01 µm (micrometers, 10^{-6} meters) and 0.1 µm, which effectively excludes all protozoa, bacteria and virus particles, as well as most proteins and high molecular weight organic compounds (Figure 7-2). Ultrafiltration is finding widespread use for a variety of applications such as producing drinking water, treating waste water and treating process water (e.g., discharges from agricultural, biotechnology, petrochemical, municipal waste streams).

Nanofiltration provides the greatest filtration capacity of the membrane technologies, with pore sizes less than 10 nm (Figure 7-2). As such, nanofiltration not only excludes those constituents separated by ultrafiltration, but also limits passage of divalent ions, dissolved organic material and sugars. Given the membranes characteristic molecular-weight cut off, nanofiltration provides for partial demineralization, which tends to yield potable water from slightly brackish water or humic-stained surface water(see Mallevialle 1996, Duranceau 2001).

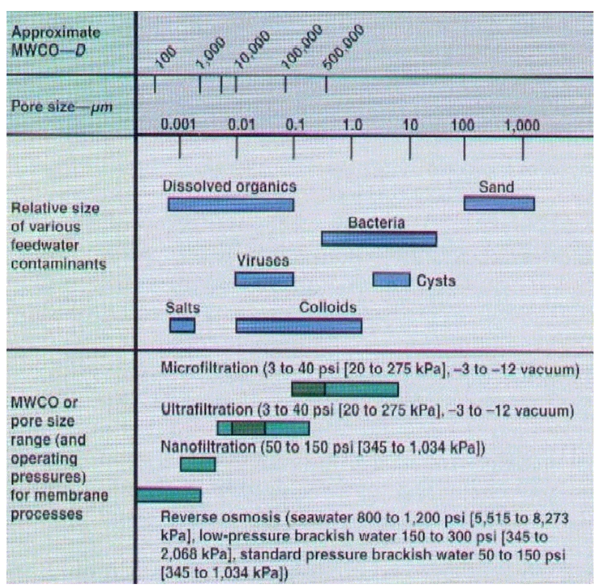


Figure 7-2. Molecular weight cut off (MWCO in Daltons [D]) values for range of filtration technologies currently available for water treatment (Source: American Water Works Association; AWWA).

Dissolved Air Flotation: An Alternative Treatment Process to Reduce Risks Potentially Associated with Interbasin Biota Transfers. USGS (2005b) completed a preliminary analysis of alternative technologies identified to reduce risks associated with biota transfers directly linked to interbasin water diversions (see DEIS, Reclamation 2005a). That initial analysis had been based on conceptual engineering designs considered by Reclamation (see 2005a,c, HE/MWH 2005), and subsequently incorporated, in part, into DEIS (Reclamation 2005a). Those conceptual designs summarized in DEIS motivated the preliminary analysis of infrastructural failure completed in this report. However, a water transmission system should be scalable and designed with sufficient flexibility to anticipate future needs that are currently unknown or poorly characterized. Given continuing advances in water treatment—including applications of "old tools" presumptively responsive to contemporary concerns—and the ever-changing technical views on "best practices" for water treatment, designed flexibility is necessary. In the current analysis, concern about biota transfer issues encourage consideration of other control measures, including those being applied to invasive species management, that can be incorporated in engineering designs considered by Reclamation as their NEPA compliance effort continues. For example, dissolved air filtration (DAF) is currently one tool being used in management of invasive species, e.g., in reducing risks of unintended biota transfers that might manifest themselves as species invasions consequent to ballast water exchanges in near-shore environments. DAF may be equally amenable to incorporation into control systems fully designed to address interbasin biota transfer issues, once alternatives of choice have been identified.

Uncontrolled releases of ballast water have become significant transport mechanisms for introduction of nonindigenous species to surface waters throughout the world (Barrett-O'Leary 1998; Carlton 1985), and reflect technical issues similar to those initially motivating concerns of biota transfers considered in USGS (2005a). As noted in USGS (2005a), species capable of successfully emigrating from Missouri River basin to Red River basin have life history attributes similar to species transferred in ballast water that enable these organism to survive in ballast water suspension or in sediment deposits of ballast tanks. Various ballast-water management strategies have been applied to control invasive species in ballast water, including a range of physical, chemical and biological treatment techniques. One engineered technology identified as an engineered unit operation for separation of nonindigenous species in ballast water is dissolved air flotation (DAF), a risk reduction tool potentially amenable to preventing potential biota transfers associated with interbasin water diversions. DAF has a long history in water treatment (Kiuru and Vahala 2001, Tchobanoglous et al. 2003), and has become a proven technology in the wastewater treatment industry for particulate separation.

Dissolved Air Flotation (DAF). Simply stated, DAF is a physical process, most often designed as an integrated unit operation intended to follow source water pre-treatment, e.g., conventional sediment-coagulation-flocculation and pH adjustment. DAF unit operations vary in their configuration with water treatment systems, and in general serve as a water clarification process that removes suspended solids from water, while minimizing use of bulk chemicals in the treatment process. In brief, DAF relies on the injection of microscopic air bubbles into a feed water stream, which causes particles to float on the surface of a basin with inclined settling plates. These particles are continuously skimmed off and removed with a wastewater stream, and is particularly useful when treating waters high in total suspended solids (TSS) or have highly variable suspended solids content. DAF is effective in removing suspended solids in the initial treatment of river and other surface waters prior to demineralization, membrane filtration and reverse osmosis (RO) and other water purification processes. Water treatment systems incorporating DAF into their design provide engineering advantages, e.g., costs reduced relative to unit operations conforming to performance criteria that exceed conventional flotation technologies. Beyond initial costs for design and construction, DAF reduces chemical costs and increases performance criteria when incorporated into routine O&M (Kiuru and Vahala 2001, Tchobanoglous et al. 2003).

In contrast to a settling process, flotation is a solids-liquid or liquid-liquid separation that results when low-density particles occur in a liquid of higher density. In general, three types of flotation have been characterized: natural, aided, and induced flotation. Natural flotation is simply a process occurring when differences in density are naturally sufficient for separation, e.g., settling or sedimentation processes. In contrast, aided flotation occurs when external forces promote the separation of particles that are naturally floatable, and induced flotation occurs when the density of particles is artificially decreased to allow particles to float. The latter process depends on the capacity for certain solid and liquid particles to link up with gas (usually air) bubbles to form "particle-gas" with a density lower than the liquid. Mechanical flotation is a general term to identify a process relying on dispersed air to produce bubbles measuring from 0.2 to 2 mm in diameter, while DAF is a form of induced flotation that relies on very fine air bubbles ("microbubbles," 40 to 70 microns). Conditions characteristic of the various different flotation processes frequently incorporated into water treatment processes are summarized in Table 7-3.

DAF processing downstream from a conventional sedimentation-flocculation-coagulation process removes solids by attaching "microbubbles" to the floc, subsequently floating solids to the surface where they are skimmed by mechanical or hydraulic means as process residuals (biosolids). Organic and inorganic chemicals or other constituents entrapped in the solids-microbubble complex such as algae, *Cryptosporidium* spp., and *Giardia* spp were reduced in concentration in the effluents leaving a DAF unit operation. A DAF pretreatment will likely reduce membrane fouling in water treatment systems using membrane technologies.

Table 7-3. Comparative attributes to distinguish DAF from other flotation processes (developed from Degrémont 1979, Kiuru and Vahala 2001, Tchobanoglous et al. 2003).

Flotation process	**Air flow* (Normal liters per cubic meter; Nl.m^{-3} water)**	**Bubble size (Units as noted)**	**Input power per m^3 treated (Watt-hours per cubic meter; Wh.m^{-3})**	**Theoretical retention time (minutes)**	**Hydraulic surface loading (meters per hour; mh^{-1})**
Aided flotation (grease removal)	100-400	2-5 mm	5-10	5-15	10-30
Mechanical flotation (froth flotation)	10	0.2-2 mm	60-120	4-16	NA
Dissolved air flotation (clarification)	15-50	40-70µm	40-80	20-40 (excluding flocculation)	3-10

*"Nl" or 'normal liter,' a unit of mass for gases equal to the mass of 1 liter at a pressure of 1 atmosphere and at a standard temperature, 0 ˚C or 20 ˚C.

NA=not applicable

Many factors influence any flotation process, including air hold-up; bubble-size distribution and carryover; degree of agitation; residence time of bubbles in source waters; solids content, particle size and gravity; shape of particle; processing of the floated product; hydration of the solid surface; and flotation reagents (see Kiuru and Vahala 2001, Tchobanoglous et al. 2003). For many applications of flotation in the waste water treatment field, it is more efficient to use microbubbles generated by nucleation of dissolved air rather than dispersed air, e.g., used for minerals and other industrial wastewater processes (Kiuru and Vahala 2001, Tchobanoglous et al. 2003). Flotation offers process advantages over sedimentation, including better treated-water quality, rapid startup, high rate operation, and thicker sludges. DAF is considered not only an alternative to sedimentation plants, but also a clarification method to improve filtration (Kiuru and Vahala 2001, Tchobanoglous et al. 2003). In dissolved air flotation (DAF), water saturated with air under pressure (3 atmospheres and greater) passes through a nozzle, thereby forming microbubbles which enter the flotation chamber, which is at atmospheric pressure. The air becomes supersaturated and precipitates out of solution in the form of tiny bubbles. In industrial scale, the supersaturated water is forced through needle-valves or special orifices, and clouds of bubbles having 0.01-0.15 mm in diameter are produced just down-stream of the constriction (Kiuru and Vahala 2001, Tchobanoglous et al. 2003). Key design considerations for DAF are consistent across a range of system configurations, but design details for any given water treatment system will depend on a number of specific factors. Several key design parameters, however, are common to DAF.

Air:Solids Ratio. The Air:Solids (A:S) ratio may be reported as a volume:mass ratio or a mass:mass ratio and will be application specific. To give an idea of the range of A:S ratios commonly applied, typical values range between 0.005-0.06 ml/mg which, at 20ºC and atmospheric pressure (say 1.0133 bar) is equivalent to 0.006 mg-0.072 mg of air per mg of solids to be removed.

Hydraulic Loading Rate. The DAF hydraulic loading rate is a measurement of the volume of effluent applied per unit effective surface area per unit time. This results in process design figures expressed as equivalent upflow velocities with units of m/h. This figure should be application specific but as a general guide the figures which should be expected would be between 2 m/h and 10 m/h. A key consideration with regard to this design parameter is whether the loading rate includes the recycled volume as well as the influent wastewater volume being applied per unit area of the system.

Typical Solids Loadings. Solids loadings are normally given in units of mass per unit area per unit time (kg/m^2-h). Typical figures encountered range from around 2 kg/m^2-h up to15 kg/m^2-h, although again the design will be application specific, depending on the nature of the solids to be removed and the extent to which chemical aids are used.

Recycle Ratio. The recycle ratio is determined as the fraction of the final effluent produced which is returned and saturated under pressure prior to entering the flotation vessel where the pressure is subsequently released and the bubbles are generated. The recycle ratio can vary immensely with recycle ratios being typically 15-50% for water and wastewater treatment application. However, for activated sludge flotation thickening, up to 150-200% recycle rates have been applied. Air dissolution rates are proportional to absolute pressure (i.e. system gauge pressure plus atmospheric pressure) in accordance with Henry's Law of partial pressures of gases adjacent to liquids. Thus, for a given application, the higher the operating pressure of the air/water saturation vessel, the lower the required percentage recycle and vice-versa. Operating pressures can therefore vary widely but are typically in the range 3-7 barg[1].

Saturation of Effluent. The production of saturated water from which the microbubbles are generated is normally achieved in two ways. The first which is common to potable water treatment involves passing the required flow of treated effluent through a packed bed system which is pressurized using a pump which is often a centrifugal pump. In systems where solids are likely to be encountered, e.g. sludge treatment, the saturation vessel is likely to be empty to prevent the fouling of any packing materials. The percentage of saturation which can be achieved will depend on the design of the system but, with good design, saturation efficiencies of up to 80-95% can be expected.

Flow Regime. To ensure that DAF systems operate as designed it is important to ensure that the system does not encounter sudden changes in the flow regime. For this reason some form of flow balancing or regulation is recommended to ensure a consistent flow rate. Another consideration is to develop a flow path through the flotation tank which ensures the maximum removal of solids via their entrainment in the air microbubbles generated.

From an engineering perspective, DAF has a long history across a range of different waters, wastewaters and sludges, with advantages over more conventional solids removal processes in many cases. Yet, there are limits to what can efficiently be removed by applying flotation technology, e.g., DAF systems are most suited to source waters where constituent solids are neutral, nearly neutral, or positively buoyant; thus the microbubbles produced in unit operations are working in concert with gravity not against it. DAF systems are capable of coping with reasonable variations in source-water quality and to a lesser extent variations in flow. Disadvantages of DAF systems include increased service and maintenance costs when compared with traditional sedimentation systems, and the increased operating costs due to the energy requirements of the system. For example, from a cost engineering perspective, DAF is a relatively high-energy consumption unit process compared to coagulation-sedimentation-filtration units. Common operating saturation pressures range between 3 and 6 atmospheres and are costly relative to other flotation processes (Kiuru and Vahala 2001, Tchobanoglous et al. 2003).

[1] "barg" is the symbol for 'bar gauge,' a common unit of pressure in engineering, which means that the pressure has been read from a gauge that actually measures the difference between the pressure of the fluid or gas and the pressure of the atmosphere.

Reduction of Biota Transfer Risk Potentially Associated with DAF. Management of invasive species has increasingly become a concern to a wide range of resource managers (see USGS 2005a), including Reclamation and stakeholders deliberating potential outcomes of interbasin water transfers potentially realized through RRVWS projects. Managing invasive species is not identical to the management of risks directly associated with biota transfers associated with interbasin water diversions, because biota transfer issues are not limited to solely to species invasions (USGS 2005a); however, from a resource management perspective, the issues are sufficiently aligned, so practices developed in response to invasive species issues may be of interest to resource managers responding to similar problems related to biota transfers.

For example, DAF has been evaluated as a risk reduction tool for managing ballast water. Typical body sizes of aquatic nuisance species (ANS) range from 0.02 to 10,000 micrometer, which represents microorganisms (protozoa, dinoflagellates, and cholera), a range of planktonic species, plants, insects, other arthropods, worms, mollusks, and vertebrates (see USGS 2005a). In bench-scale studies DAF was evaluated as an option for managing ballast water control (see, e.g., J. Sansalone at http://sgnis.org/publicat/sansalon.htm and E.C. Voon http://etd.lsu.edu/docs/available/etd-0905102-143754/unrestricted/Thesis-Voon.pdf#search=%22%22new%20zealand%22%20%22dissolved%20air%22%20%22invasive%20species%22%22 last accessed September 18, 2006). Ballast water surrogates representative of aquaculture, fresh water, wastewater, and storm water sources were experimentally manipulated to a similar turbidity range before application of DAF treatment. Results of these bench-scale experiments for ballast water surrogates based on particle number demonstrated particle removal efficiencies as high as 98% for the freshwater matrix. Additionally, particle size distributions in DAF were modeled using a two-parameter power law function, yielding an index of surface area concentration that suggested both influent and effluent particle distributions followed a graded response with respect to removal. Overall, the study demonstrated the potential of DAF as a competitive and effective size-based separation technology (Vong 2002).

Examples of DAF being used to address concerns related to biota, e.g., disease-causing agents, in source waters illustrate how integrated water treatment systems may be developed to reduce risks of biota transfers, if interbasin water diversions between Missouri River and Red River basins occurs in the future. For example, New Zealand Ministry of Health (2001; http://www.moh.govt.nz/moh.nsf/c43c7844c94e08cd4c2566d300838b43/5af58e090cf4098bcc25699600754798?OpenDocument, last accessed July 25, 2006) provides guidance for DAF as part of a water treatment system focused on managing risks for drinking water supplies. Their guidance considers coagulation, flocculation and DAF for removing particles (including *Giardia*, *Cryptosporidium*, and similarly sized organisms) and natural organic matter from source waters, suggesting that the combination of water treatment processes could be valuable where low-density particles, e.g., nuisance algae, are to be removed. As guidance supporting water management, failures within water treatment systems were considered, e.g., if coagulation-flocculation-flotation processes did not attain performance criteria, then a range of scenarios were evaluated through a process similar to that followed in the current and earlier investigations (see, e.g., USGS 2005a). New Zealand guidance suggested that coagulation-flocculation-flotation process and their attendant risks cannot be viewed in isolation, e.g., how well the process works affects operations that follow in a water treatment series, which subsequently effect outcomes, e.g., related to increased incidence of disease. The guidance observed that several factors influence the effectiveness of the coagulation-flocculation-flotation process, including the quality of the source water (e.g., waters with little turbidity or of variable quality make good coagulation difficult) and the composition of the organic matter affects coagulant and flocculant type and their dose control (e.g., poor dose control is likely to cause poor floc formation). In summarizing risks associated with DAF used in conjunction with coagulation and flocculation, the event creating the greatest risk involved under performance or failure in the coagulation-flocculation-flotation process that yielded poor removal of particles. The most important preventive measure was assuring that chemical dosing was controlled to match changing raw water quality and quantity. In addition to evaluating risks potentially realized consequent to system failure, a range of countermeasures were presented, e.g., as critical components in routine O&M procedures. The summary countermeasures were considered through causal chains, e.g., linking causes for system failure with preventive measures, and corrective actions to mitigation risks. In developing their guidance, New Zealand Ministry of Health pursued a HACCP process similar to that previously characterized to foster development of a pre-emptive risk management focused on biota transfers potentially associated with interbasin water diversions (see, e.g., http://www.haccp-nrm.org/ and ASTM 2006d).

Summary of DAF for reducing risks of biota transfer. Flotation processes separate suspended inorganic, biological or organic particles from a liquid phase, a process that may be facilitated by the addition of a gas phase to the liquid phase, usually through the addition of air in the form of fine bubbles as in DAF. In DAF the rising bubbles either adhere to or are trapped in the particle structure, resulting in an increase in the buoyancy and a flotation of the bubble-particle complex, reinforcing the observation that separation by flotation depends as much on the surface properties of the particle as the size and the relative density of the particles. In the past 30 years, DAF has been successfully applied to waste treatment to remove suspended solids, grease, oil and biological solids from wastewater, and in the past 10 years has been applied to management of invasive species. In DAF a gas phase of fine bubbles is produced from a solution supersaturated with air. Once released, these microbubbles contact suspended particles suspended in source water, and the air-particle complex rises to the surface where it is skimmed off, and the clarified liquid is withdrawn from the bottom of the DAF unit. Dissolved-air bubble sizes are smaller, ranging from 1 to 100 microns. Primary design variables include pressure, recycle ratio, influent solids concentration, water quality such as salinity, surface tension, temperature, residence time and the addition of coagulant or surfactants. Suspended biological particles and sediment characteristics of importance include particle-sediment size, volume or number concentration, and particle specific gravity.

7.2.5 Risk Reduction and Action Alternatives Relying on Missouri River Source Waters. As noted in USGS (2005b), risk reduction related to interbasin water diversions considered as Action Alternatives in the DEIS may be simplified by considering (1) where treatment occurs, and (2) physical and chemical characteristics of the treatment process and conveyance infrastructure. This summary of our preliminary analysis of failures in water transmission systems in part reflects an extension of that risk reduction analysis (USGS 2005b).

Withdrawal of Source Waters, Biota Treatment, Transmission Infrastructure and Action Alternatives in DEIS. Each of the action alternatives described in the DEIS have incorporated a biota-water treatment plant in the Missouri River basin either near the McClusky Canal or near Bismarck, North Dakota (see Figure 7-3 through Figure 7-6). Consequently, spatial attributes of risks for basin-wide scales largely remain relatively insufficient for discriminating one alternative or another as being more or less “risky,” since withdrawal and treatment occurs in Missouri River basin prior to water diversion to Red River basin in each alternative.

How water is withdrawn from these sources may be more critical to the evaluation. As currently proposed, methods for source water withdrawal differ across action alternatives which may influence risks realized in water transfers from Missouri River to Red River basins.

Source water withdrawal. As noted in USGS (2005b) and summarized in greater detail in Reclamation (2005a,b,c,d; see also HE/MWH 2005), Action Alternatives targeting source waters at McClusky Canal have incorporated a “wet-sump” pumping plant for an open-water intake (Reclamation 2005b, Figure 7-3). For the Missouri River Import to Red River Valley Alternative, Reclamation has proposed using a radial collector-well design (Figure 7-4, Figure 7-5, and Figure 7-6) to withdraw the water from Missouri River source by placing wells in the alluvium under the direct influence of the river. In this application, radial-collector wells provide filtration through the alluvium and present characteristics similar to a sand filter (Letterman 1999, Joshi 1991). Direct surface water withdrawals such as that at McClusky Canal lack the filtration capacity of radial-collector wells; hence, the design of withdrawal of source water should provide an additional barrier to biota transfer prior to water treatment. In addition to filtration provided by radial-collector wells, source water delivered to the biota-water treatment plant proposed for this Action Alternative may be of higher quality than those waters drawn from McClusky Canal, because surface water sources may present greater variation in water quality, e.g., due to seasonal flow volumes in source waters of the Missouri River. Although seasonal variation is water quality may be reduced through a tap to ground water associated with the alluvium, ground water pumped from the sand and gravel aquifers along the Missouri River will leach iron, manganese, and calcium carbonate salts which cause tase and odor problems along with discoloration and staining problems and hardness. These raw water issues associated with alluvial ground water may be addressed by pretreatment processes relying on addition of potassium permanganate which will precipitate the metal salts and lime added to remove hardness in the conventional treatment process. Filtration and potential for chemical contaminant attenuation achieved by alternatives relying on radial-collector wells may also reduce water treatment costs, e.g., number of chemical treatment processes, required of product water, when considered from a system perspective.

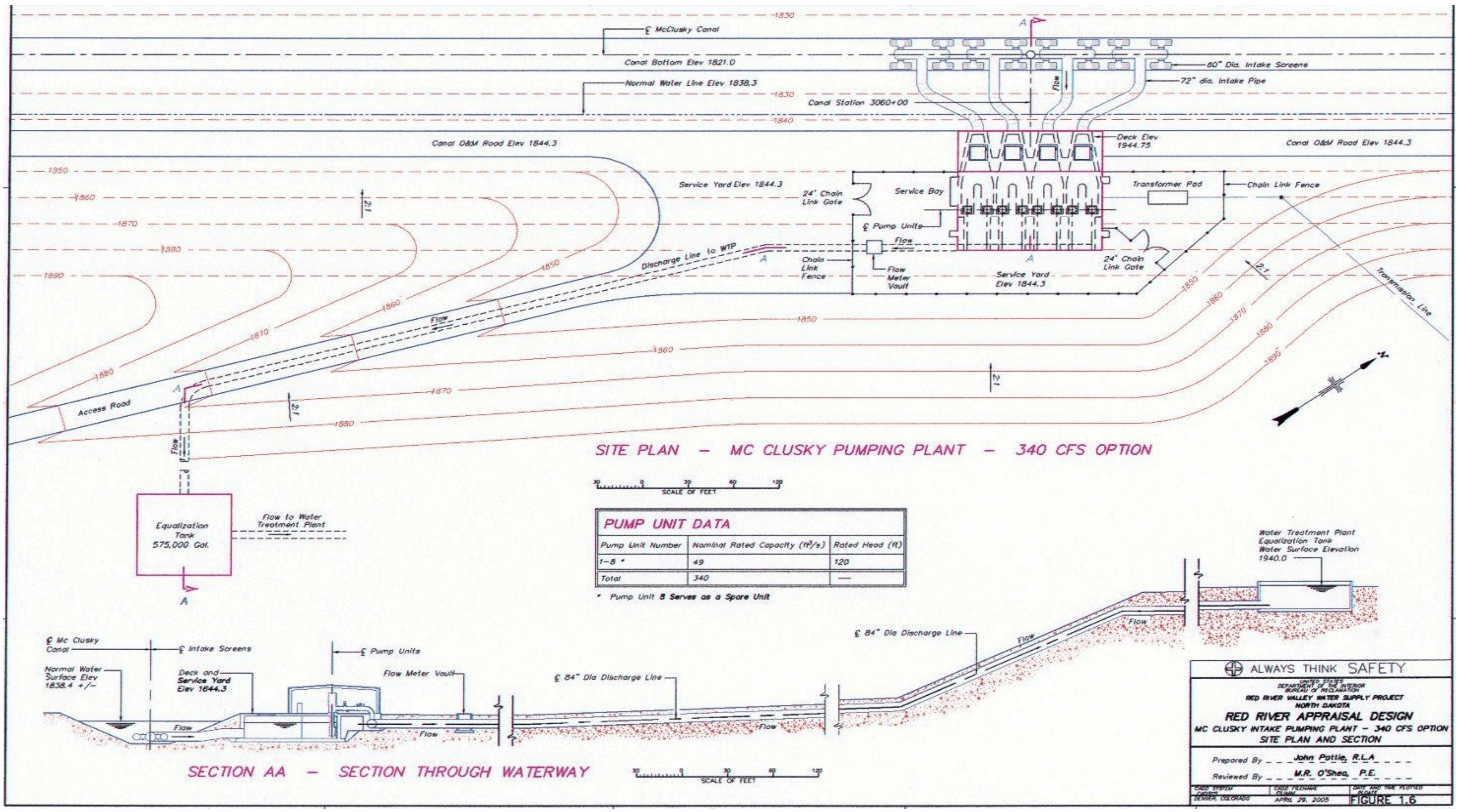


Figure 7-3. Preliminary proposed intake pumping plant on McClusky Canal for selected action alternatives (from Reclamation 2005).

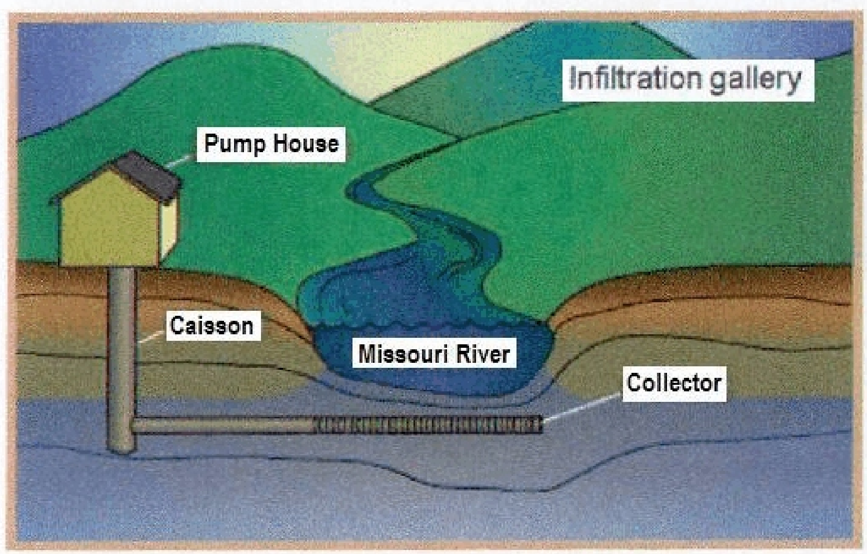


Figure 7-4. Conceptual illustration of radial-collector well placement for withdrawal of source waters from Missouri River near Bismarck under one action alternative (modified from http://water.montana.edu/training/obpdf/Unit04.pdf).

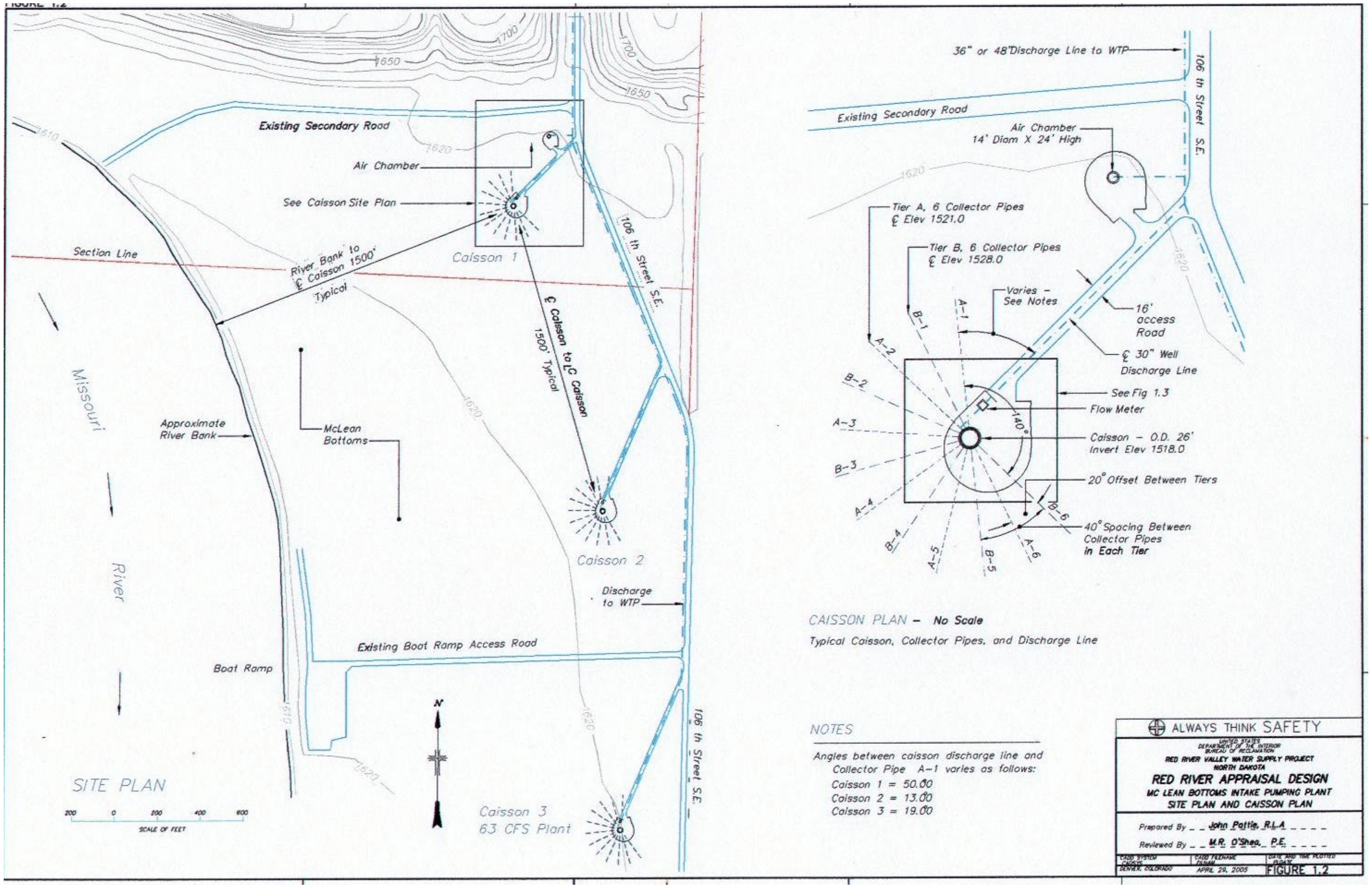


Figure 7-5. Proposed design for radial-collector wells located near Bismarck for withdrawing Missouri River source waters via alluvial aquifers directly influenced by river (from Reclamation 2005).

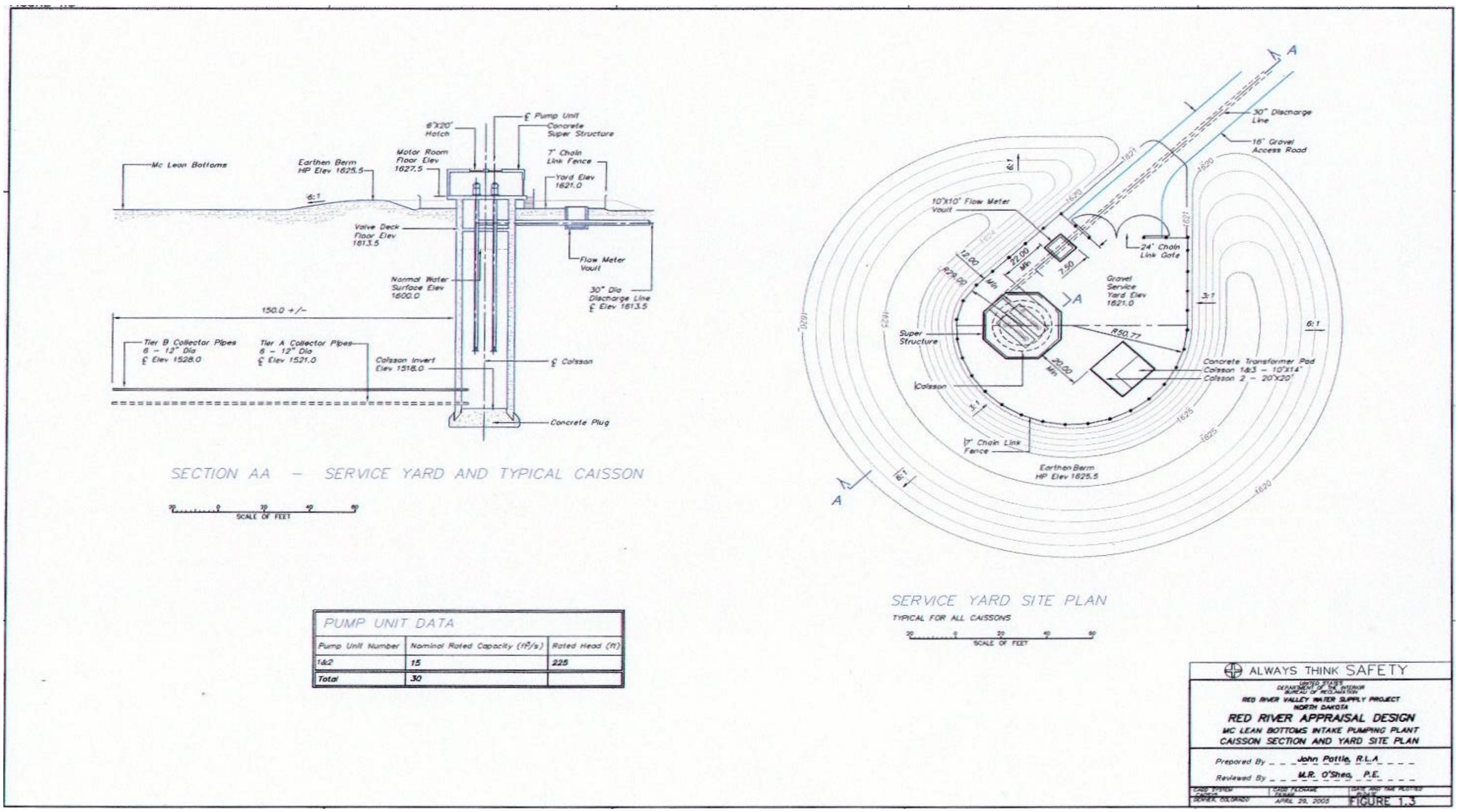


Figure 7-6. Preliminary proposal for individual caisson unit and associated array of radial-collector wells (from Reclamation 2005).

Buried pipe. A transmission system of buried pipe has been briefly characterized in the DEIS (Reclamation 2005) for each in-basin and interbasin Action Alternative. Miles of buried pipe are required for each alternative. The extent of piping involved depends on the design features of the particular alternative, ranging from a low of approximately 130 miles (205–210 km) to a high of approximately 600 miles (950–955 km) for the GDU Import to the Sheyenne and GDU Supply Replacement Pipeline, respectively (see Section 1, Table 1-2 and Section 4, Table 4-1). The GDU Supply Replacement Pipeline has a configuration that resembles a distribution system more than a simple transmission system (see Moser 2001 for coarse distinctions between transmission and distribution pipelines), this alternative shares a common design feature with the GDU Import and Missouri River Import to Red River Valley alternatives—each of these transmission pipelines terminates with existing distribution infrastructure. GDU Import to Sheyenne River delivers treated source waters to an open-water system designed as part of the transmission system, while Lake Ashtabula serves as a storage-regulating reservoir in Action Alternatives except the GDU Pipeline Alternative. GDU Pipeline Alternative directly terminates at existing distribution nodes in, e.g., municipalities in Red River Valley. Regardless of the differences and similarities in these preliminary transmission system designs, the performance of buried pipe brings is well documented for water transmission and distribution networks. As a result, risks associated with buried pipelines and surface pipelines are relatively well characterized, and risk management practices well developed (see, e.g., Deb et al. 1995, Gagliardi and Libertore 2000; Moser 2001, American Water Works Service Company 2002, NRC 2005). Past experience and these existing practices benefit the risk management needs confronting Reclamation and stakeholders sharing a common interest in water transfers and the Red River Valley.

Buried water transmission, distribution, and wastewater pipelines are subject to corrosion, soil movements, temperature fluctuations, rainfall, and system stresses in the continuous process of structural deterioration. The simple summary of threats to a water transmission and distribution system included in Section 2 is revisited in Table 7-4 (adapted from Electric Power Research Institute, or EPRI [2001], as cited at http://www.structint.com/tekbrefs/datasheets/buriedpiping/). Features common to buried pipe and system components such as pumps and valves potentially link shared attributes of the transmission and distribution systems, e.g., through similarities in materials of manufacture or their role in the control system serving the interbasin water diversion infrastructure. These attributes may be time-independent, time-dependent, or related to pipe materials independent of the system of which they are part (e.g., PVC pipe has physical attributes that influence life span independent of its use). For example, regardless of the materials used in their manufacture (DIP, ST pipe, or PVC pipe), buried pipelines are subject to significant

Table 7-4 General listing of concerns related to failure analysis for buried pipelines (adapted from EPRI 2001, see also Section 2).

Time-dependent Attributes	Time-independent Attributes	Materials Attributes
External Corrosion (soil interactions with pipe exterior) ● General corrosion ● Localized corrosion (pitting, crevice, and intergranular attack) ● Microbiologically-influenced corrosion ● Galvanic corrosion ● Environmentally-assisted cracking and corrosion fatigue ● Stray current	Mechanical Damage ● Outside party (e.g., other vendors) ● Installation ● Previously damaged	Manufacturing Related ● Defective Pipe Seam ● Defective Pipe ● Wrinkle bend or buckle ● Stripped threads/coupling failure
Internal Corrosion (water interactions with pipe interior) ● General corrosion ● Localized corrosion (pitting, crevice, and intergranular attack) ● Dealloying ● Microbiologically-influenced corrosion ● Galvanic corrosion ● Environmentally-assisted cracking and corrosion fatigue	Incorrect Operations ● Operator error ● Incorrect operating procedure ● Over pressurization (potentially yielding pressure surge, e.g., upon correction)	Welding Fabrication Related ● Defective pipe girth weld ● Defective long seam weld
Fatigue (pipe material aging) ● Pressure cycling (with associated pressure surges) ● Thermal cycling	Outside Force ● Earth movements ● Heavy rain, floods	Equipment ● Gasket O-ring ● Control/relief equipment malfunctions ● Seal/pump packing failure ● Miscellaneous
Heavy fouling/clogging (deposition on pipe inner walls)		

degradation from various internal and external corrosion mechanisms or from differing responses to pressure transients that lead to maintenance and repair issues, especially as the transmission or distribution system ages. Depending on pipe specifications and materials and as piping ages, pipe and pipe coatings deteriorate (e.g., corrosion for ferrous pipe and other mechanisms for non-metallic, non-ferrous materials such as PVC) which eventually leads to leaks or pipe breaks, or corrosion in mechanical components of the system.

Piping systems such as those proposed for addressing water needs of the Red River Valley—regardless of their application in No Action or Action Alternatives—contain miles of buried piping whose failure can adversely impact transmission or distribution lines. As standard practice suggests (see, e.g., Moser 2001 and references cited therein), buried pipe will generally be placed no less than 7-7½ feet below ground surface (BGS) in North Dakota to prevent freezing. In the northern Great Plains, frost-heaving will be reduced if burial follows guidance available for construction on various soil types (see, e.g., see http://www.soils.usda.gov/technical/ handbook/contents/part618p2.html#29, Andersland Ladanyi 2004, USDA–NRCS 2003, see also ANSI/AWWA D103-80), depending on required elevations for pipeline segments throughout the transmission system. Other components of the control system, be that from the source-water withdrawal module, source-water treatment module, or other components of the transmission module are also critical with respect to their sighting, if system performance is maximized.

Pipe standards for materials and installation are specified by American Water Works Association (AWWA; see, e.g., http://www.awwa.org/bookstore/Category.cfm?cat=3), American Society for Testing and Materials (ASTM; see, e.g., http://www.astm.org/cgi-bin/ SoftCart.exe/COMMIT/COMMITTEE/C13.htm?L+mystore+jvks6413+1125547345, last accessed August 31, 2005), and American Society of Civil Engineers (ASCE; see, e.g., http://www.asce.org/ instfound/codesandstandards.cfm, last accessed August 31, 2005). For example, transmission and distribution lines may be constructed of a variety of materials, but must withstand, e.g., internal and external pressures, including transients/surge (water hammer) and be resistant to corrosion. Under a variety of specifications, materials for pipeline construction include welded steel, PVC, HDPE, and ductile iron of several standard thicknesses to handle different pressure loads. For buried pipe, push-on (gasketed) joints are commonly used, e.g., for ductile iron, welded steel, and PVC pipe, to provide a range of flexibility which reduces breaks associated with earth movements such as settling or creep. Polyvinyl chloride (PVC) pipes are increasingly found in distribution networks wherein light-weight materials having good hydraulic characteristics in diameters up to 48 inches. For a more thorough discussion of general attributes of water transmission and distribution systems refer to Nayyer (2000) and Moser (2001) and standards and references cited therein.

Water management agencies use their transmission and distribution systems to deliver high quality water in the face of breaks, corrosive deterioration, and other forces affecting system integrity. Resource managers will need to address the management issues when considering pipeline designs proposed under the Action Alternatives. Water transferred via pipeline from either the open-water intake and biota-treatment plants at McClusky Canal or the radial-collector wells and biota-treatment plant near Bismarck will be high quality water. Any of the systems detailed in the Action Alternatives, however, will be subject to aging throughout the water transmission and distribution network that is variously spread over large geographic areas with multiple connections, e.g., to existing municipal and rural distribution systems. Recently, numerous reports have been published, especially following implementation of the SDWA, with focus on the increasing awareness of aging water transmission and distribution system infrastructure. These studies indicate that regardless of the no-action, action alternatives or other system configurations considered to satisfy water needs of the Red River Valley, water resource managers must have in place a process to assess, plan, locate and repair problems, and update their water transmission and distribution systems periodically.

The potential for pipe breaks and the risks that might be associated with subsequent biota transfers are low probability-high consequence events potentially linked to the transmission and delivery of treated water. As one type of control system failure, pipeline breaks and their role in the "life cycle" of a water transmission network should be incorporated into long-term management plans for the water system regardless of the alternative selected. Once an alternative is selected to meet water needs of the Red River Valley, engineering designs can go beyond industry-wide experience, e.g., based on existing information on pipe breaks (see Section 3; see also, Deb et al. 1995, for example), and system-specific data may be collected that reflects failure rates of systems or system components specific to the system to be built. Once built, life-cycle management of buried pipe should assess the condition of buried pipe throughout the course of the network, manage and mitigate the network's deterioration, and develop safe and cost-effective asset management plans to minimize unexpected outages and minimize long-term costs, be those monetary or primarily non-monetary, e.g., related to collateral events such as biota transfers.

Engineering Attributes of Water Transfer Control Systems and Risk Reduction. Each proposed biota-water treatment plant is predicated on disinfection of source waters to reduce risks associated with unintended biota transfers potentially resulting from interbasin water diversion. Reclamation considered a range of biota-water treatment options as potential alternatives prior to selecting those developed in the DEIS (see Reclamation 2005c). As described in the DEIS, disinfection is a key component in each Action Alternative and provides a range of water treatment technologies to reduce risks of biota transfers potentially associated with interbasin water diversion. Each of the Action Alternatives includes a conventional pretreatment that involves coagulation, flocculation, and sedimentation.

Disinfection and Risk Reduction. USGS (2005a,b and references therein) provided a brief background on disinfection characterization and various chemical and physical options currently used in water treatment pursuant to regulatory requirements of SDWA and its amendments. For example, under SDWA as amended, EPA has regulations that specify minimum acceptable pathogen inactivation necessary for public water to be considered potable, including regulations that specify minimum disinfection of (1) 3 log (99.9%) for *G. lamblia* cysts and (2) 4 log (99.99%) for enteric viruses (see Letterman 1999, see also http://www.epa.gov/safewater/sdwa/index.html last accessed April, 2006). Water quality characteristics influence disinfection processes, e.g., turbidity and pH strongly affect contact time necessary to achieve target level of disinfection. Microorganisms have varying sensitivities to disinfectants. If an organism has a high resistance to a certain disinfectant, required contact time will be greater than for an organism with a low resistance. There will also be potential for growth of resistant forms such as in biofilms formed in the transmission system.

Depending on the final design specifications of the treatment system (e.g., regulatory requirements or engineering costs, if regulatory requirements are variously achieved across a range of acceptable treatment options), various levels of disinfection can be attained by altering the type and concentration of disinfectant and contact time, or type of physical barrier (e.g., membrane filtration) incorporated into system's design. For example, selection of disinfection technology can be determined once regulatory and management needs are addressed, and once the level of disinfection is specified, engineering designs can be modified to yield the necessary contact time for a given level of disinfection.

Initial characterization of risk reduction in Action Alternatives involving interbasin water diversion. USGS (2005b) summarized the initial evaluation of "risk reduction credits" that are associated with each of the Action Alternatives (see USGS 2005b). In USGS (2005b) the analysis of the water transmission system was considered as discrete compartments in a categorical analysis (see Appendix 4, USGS [2005a]) wherein Action Alternatives were scored for means of water withdrawal, location of treatment plant, extent of pre-treatment and disinfection, and release to the environment (e.g., was the system contained throughout the transmission and distribution network). In the current analysis, a number of uncertainties and assumptions regarding each alternative and risks associated with these alternatives must be incorporated into interpretative context for refining subsequent iterations of risk reduction analysis (see Section 7.3). While the preliminary risk reduction analysis acknowledges differences among Action Alternatives (USGS 2005b), the summary findings therein reflected assumptions of risks being identical across systems, e.g., risks of pipe breaks as measured by "breaks per pipe-mile per year" are assumed identical across the range of pipe materials and sizes summarized in Reclamation (2005b,c). These assumptions became the focus of this analysis, which should better position future engineering risk and failure analyses based on greater specification across pipe materials, component parts of the transmission system such as pumps, valves, and pipe configurations, and routing details that might affect risks linked to future system failures. Section 7.2 provides an initial interpretation of existing data compiled and summarized in Section 3.

7.3 Summary and Characterization of Potential Failures and Their Associated Risks

A preliminary risk-reduction analysis of Action Alternatives outlined in DEIS (Reclamation 2005a) observed that differences in risk reduction scores across interbasin water transfer Action Alternatives were relatively small. The GDU Water Supply Replacment Pipeline presented greater risk reduction that other interbasin transfer Action Alternatives, although its reliance on a pipeline of varying diameters suggested hydraulic conditions and pipe integrity could offset risk reduction credits associated with the configuration. USGS (2005b) also observed that open-water conveyance of treated waters via the Sheyenne River adversely affected the risk reduction credit score for the GDU Import to Sheyenne River alternative, and could potentially limit alternatives relying on Lake Ashtabula as storage reservoir. The following characterization of risks associated with system failure is preliminary and extends the risk reduction analysis (USGS 2005b) that lead to this current investigation.

7.3.1 Overview of failures potentially influencing risks of biota transfer. As captured in Section 3, existing data compiled and maintained by industry and government sources suggest failure rates for any of control system presented in DEIS (Reclamation 2005a) are readily available for a preliminary analysis Action Alternatives. If all parties—governmental decision makers and stakeholders active in the NEPA process—agree on specifications of, e.g., “acceptable risk” and risk management strategies to mitigate those risks, empirical data should be sufficient to winnow the list of Action Alternatives for addressing water needs and demands of the Red River Valley to 2050.

The following summary presents a brief comparison of Action Alternatives, especially with respect to conceptual design differences (e.g., pipeline configuration, reliance on open-water components, differences in water intake, and comparison of UV disinfection and microfiltration as those tools are related to disinfection capabilities). As in USGS (2005a,b), engineering costs analysis is not incorporated into these comparison, since those efforts may be better served with a full engineering design.

Pipeline configuration. From a technical perspective, the preliminary risk-reduction analysis completed by USGS (2005b) acknowledged that a simple tally of risk-reduction credits should be extended, based in part on differences in conceptual routings of pipeline across each Action Alternative involving an interbasin water diversion. For example, DEIS (Reclamation 2005a) identified quantities of pipe required for each Action Alternative, and those estimates were considered categorically as one factor potentially influencing risk differentially across these engineering alternatives. When considered in light of the primer on fluid dynamics and the flow of water through pipes (Section 2), an initial analysis of pipeline configuration and its affect on risk may be captured by turning to first principles of fluids moving through pipes (see, e.g., Larock et al. 2000, Mays 1999, Simon and Korom 1997, Tullis 1989).

Given the range in pipe diameters and length of pipeline presented across the Action Alternatives potentially involved with an interbasin water transfer (see Reclamation 2005a; see summaries applicable to this analysis, Table 7-5), the relationships among pipe diameter, volume of water potentially being conveyed as a function of pipe diameter (here, cross-sectional area for pipes of specified diameters), and the potential linkages between these interrelated factors and pipe failures (e.g., as leaks, breaks or bursts; see Section 2), a simple breakout of “failure categories” discriminates pipeline configurations beyond a simple measure of length (Table 7-5). Based on cross-sectional surface area (Figure 7-7), a simple categorization of pipe diameters was developed. Breakout categories “1,” (blue) “2,” (green) “3,” (yellow) “4,” (orange) and “5” (red) simply captured 90th, 75th, 50th, 25th, and 10th percentiles, respectively, of pipe diameters (as a function of cross-section area) currently projected for use in Action Alternatives. As empirically-based studies and standard references suggest, within a given material—DIP, ST pipe, or PVC pipe—small diameter pipe generally tends to have higher breakage rates than large diameter pipe (Larock et al. 2000, Mays 1999, Simon and Korom 1997, Tullis 1989). Given this inverse relationship between pipe diameter and breakage rate, categories “1” (blue) through “5” (red) simply represent decreasing pipe diameters linked to increasing rates of pipe breaks. Data on pipe failure has been compiled by government and industry sources, and discrimination is largely focused on pipe materials and the apparent relationships between breaks and bursts, and pipe material and manufacturing processes (e.g., cast iron *v.* ductile iron). Also, the majority of these data presently consider pipe breaks and bursts as length-time normalized values (e.g., pipe breaks/100 km/year; see Section 3) without records categorized by pipe diameter. However, for this preliminary analysis data are sufficient to draw conclusions regarding pipe materials and pipeline configurations currently envisioned for interbasin water transfers outlined in the DEIS (Reclamation 2005a).

Box plots of existing data available for the current analysis (see Section 3) suggest that rates of pipe failures (as breaks and bursts) are similar for DIP and ST pipe (e.g., median values, 6.0 and 6.7 breaks/100 km/year), and for large diameter piping, material of choice may be determined by criteria other than a simple reliance on past performance measured as “pipe breaks.” While restrictions due to pressure classification will limit the use of PVC pipe in any water transmission system, the existing data on pipe breaks and bursts rates for this pipe material suggests its performance will likely outpace that of DIP and ST pipe (e.g., median value, 1.7 breaks/100 km/year). Reliance on a single measure of performance such as break or burst rate, however, oversimplifies the engineering picture for designing and developing any water transmission or distribution system, and these general findings apparent in this preliminary failure analysis are intended to identify trends that might warrant further consideration in project development. For example, a simple project-specific interpretation of the available data might be, for large diameter reaches of a transmission system, engineering specifications for piping may focus on other strengths and weaknesses of DIP and ST pipe beyond a simple metric of break and burst rate for deciding which material would best fit project needs. The choice of DIP or ST pipe may be driven by criteria other than pipe failure. Similarly, smaller diameter piping may warrant consideration of PVC as pipe material of choice, given the material’s historic performance record. Again, a sole reliance on break and burst rate oversimplifies the engineering design process, but from the preliminary analysis, PVC pipe is clearly competitive within the context of reducing risk associated with pipe failure.

Caution is urged regarding the potential oversimplification of specifications, e.g., of pipe material, in part, because of the widely divergent conceptual designs presented in DEIS (Reclamation 2005a). As the color-coded summary table (Table 7-5) and companion Figure 7-7 and Figure 7-8 suggest, simple linear transmission systems such as the GDU Import to Sheyenne would require specification quite different than that for, e.g., GDU Water Supply Replacement Pipeline (LAP). For example, while GDU Import to Sheyenne pipeline is relatively short (less than 150 miles in length) and consists of large diameter pipe, GDU Water Supply Replacement Pipeline is greater than four times as long, consists of a wide range of pipe diameters, and is hydraulically more complex. As Figure 7-8 and Table 7-5 indicate, the widely divergent characteristics of the transmission system (as captured by percentile plots and wide range in color codes, respectively) must be acknowledged in fully developed engineering designs, because these divergent configurations would present markedly different risks for biota transfers linked to system failures associated with, e.g., pipe breaks or bursts.

Figure 7-7. Evaluation of potential failure-rate differences across a range of pipe diameters occurring in various pipe configurations proposed in Action Alternatives.

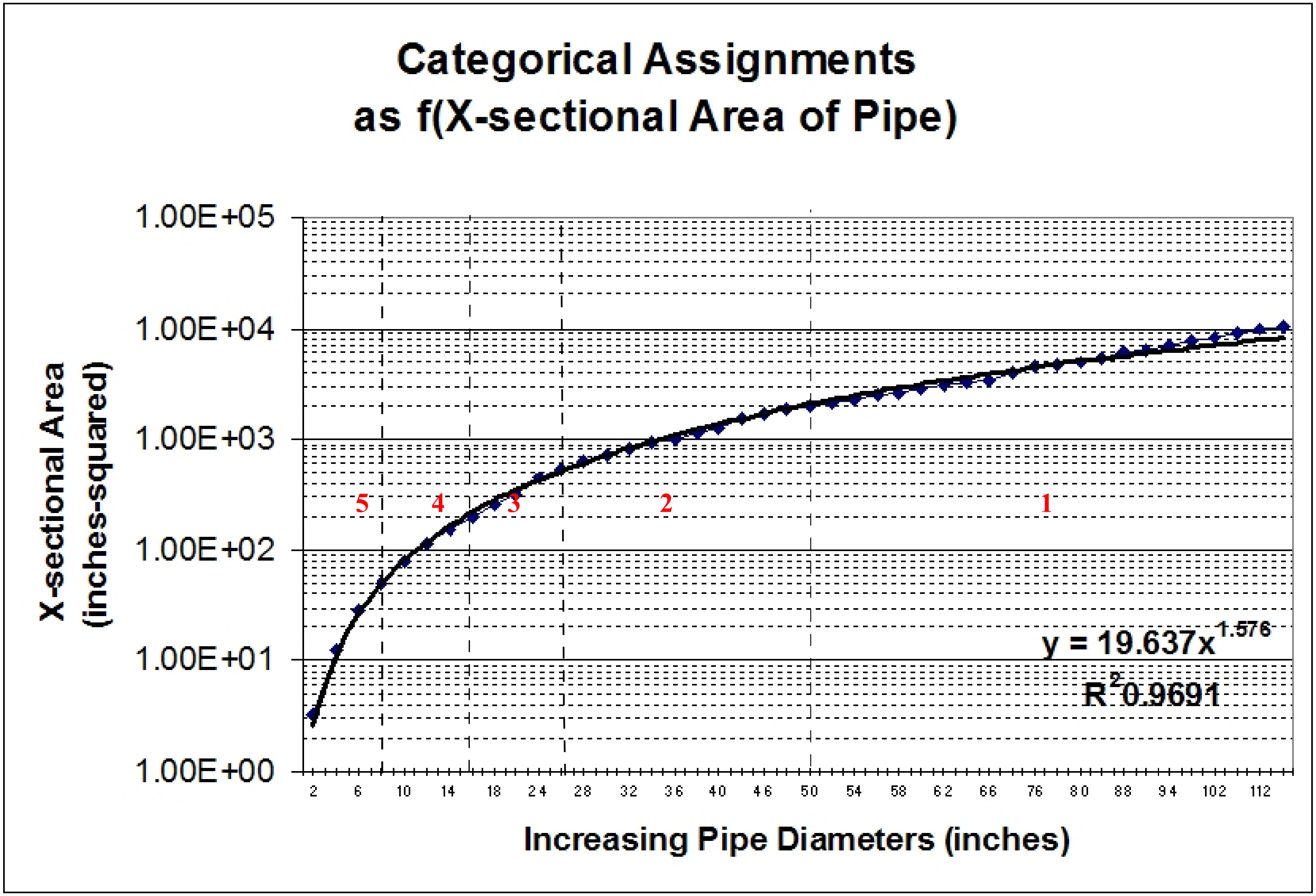

Categorical Assignments
as f(X-sectional Area of Pipe)
X-sectional Area (inches-squared)
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
5
4
3
2
1
y = 19.637x^1.576
R² 0.9691
2 6 10 14 18 24 28 32 36 40 46 50 54 58 62 66 76 80 88 94 102 112
Increasing Pipe Diameters (inches)

Figure 7-8. Graphic plot of percentile values of pipe diameters occurring in Action Alternatives under scenarios developed in DEIS (Reclamation 2005a).

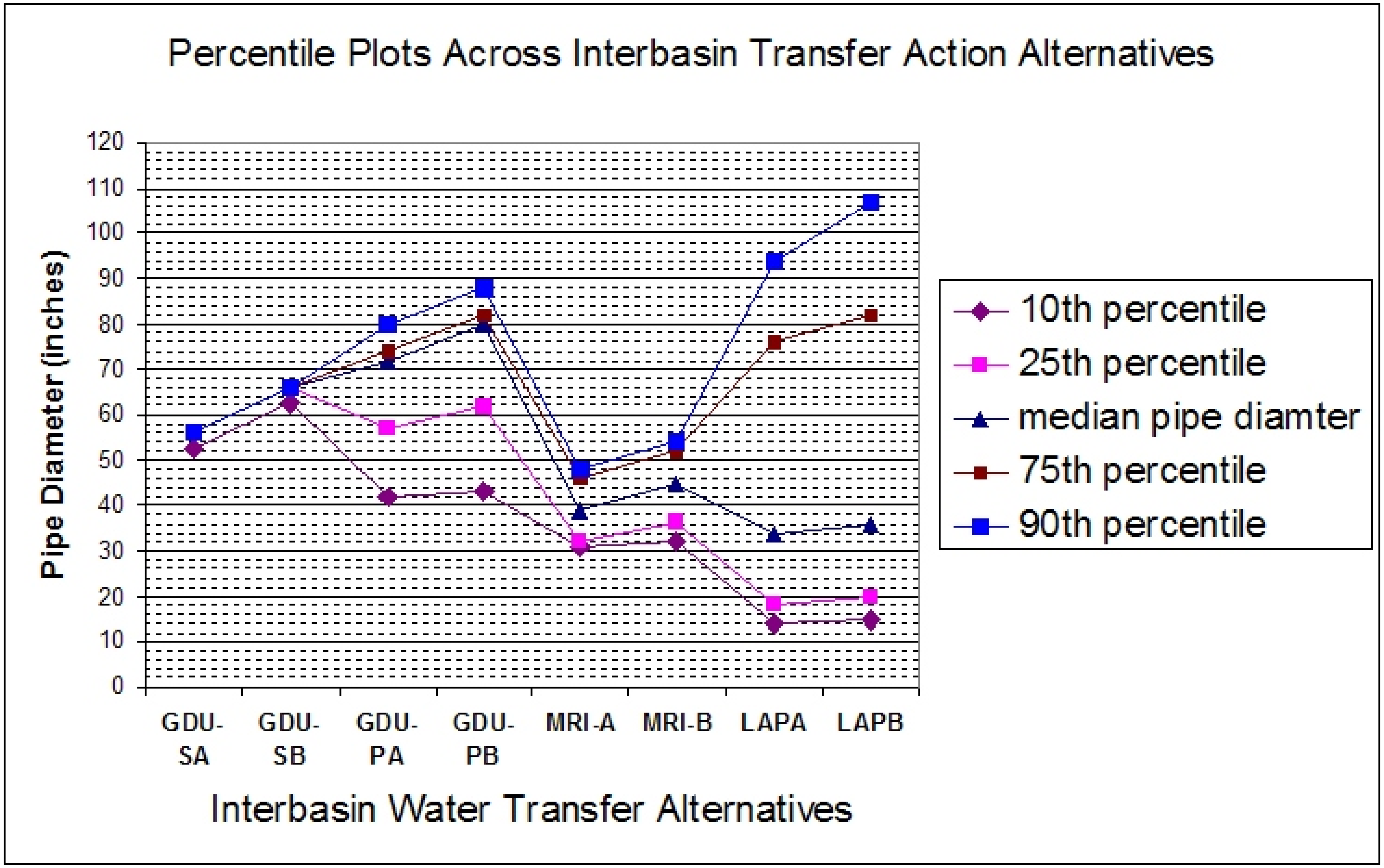

Percentile Plots Across Interbasin Transfer Action Alternatives
Pipe Diameter (inches)
0
10
20
30
40
50
60
70
80
90
100
110
120
GDU-SA
GDU-SB
GDU-PA
GDU-PB
MRI-A
MRI-B
LAPA
LAPB
Interbasin Water Transfer Alternatives
10th percentile
25th percentile
median pipe diamter
75th percentile
90th percentile

Table 7-5. Comparisons of preliminary pipeline configurations with primary discrimination based on simple estimates of risk captured empirical data reflecting pipe-break trends linked to pipe diameter (here, as cross-sectional area).

Categorical code	Color designation
1	Lowest risk
2	
3	Moderate risk
4	
5	Highest risk

GDU Import via Sheyenne River*

Scenario A			Categorical Score based on pipe diameter	Scenario B			Categorical Score based on pipe diameter
County	**Pipe diameter (inches)**	**Pipe length (feet)**		**County**	**Pipe diameter (inches)**	**Pipe length (feet)**	
Sheridan	50	62,818	3	Sheridan	60	62,818	2
Sheridan	56	51,758	2	Sheridan	66	51,758	2
Wells	56	200,112	2	Wells	66	200,112	2
Foster	56	189,552	2	Foster	66	189,552	2
Griggs	56	174,768	2	Griggs	66	174,768	2
	Total pipeline length	679,008	11		Total pipeline length	679,008	10
Sheyenne River	**Open conveyance**	**15,840 (approximate river-miles in feet)**		**Sheyenne River**	**Open conveyance**	**15,840 (approximate river-miles in feet)**	

*Both scenarios involve open-conveyance transfer of treated water (e.g., UV irradiated or filtered via microfiltration system) which increases risk of biota transfer, although a quantitative estimate of that increased risk largely depends on system actuals that are yet to be fully designed and specified; hence, numeric or categorical estimates of risk are not included in this summary table. Absence from this table acknowledges uncertainty in the magnitude of additional risk associated with reliance on open conveyance, but absence must not be regarded as insignificance.

GDU Import Pipeline							
Scenario A			Categorical Score based on pipe diameter	Scenario B			Categorical Score based on pipe diameter
County	Pipe diameter (inches)	Pipe length (feet)		County	Pipe diameter (inches)	Pipe length (feet)	
Sheridan	72	62,818	2	Sheridan	80	62,818	2
Sheridan	72	51,758	2	Sheridan	80	51,758	2
Wells	72	119,561	2	Wells	80	119,561	2
Wells	80	80,551	2	Wells	88	80,551	2
Foster	80	189,552	2	Foster	88	189,552	2
Griggs	80	129,888	2	Griggs	88	129,888	2
Steele	80	19,015	2	Steele	88	19,015	2
Steele	72	107,705	2	Steele	80	107,705	2
Traill	72	87,773	2	Traill	80	87,773	2
Traill	48	78,641	3	Traill	48	78,641	3
Traill	60	80,690	2	Traill	66	80,690	2
Grand Forks	48	79,579	3	Grand Forks	48	79,579	3
Grand Forks	36	13,486	3	Grand Forks	38	13,486	3
Polk	18	43,712	4	Polk	20	43,712	4
Cass	60	25,846	2	Cass	66	25,846	2
Cass	60	189,465	2	Cass	66	189,465	2
	Total pipeline length	1,360,040	37		Total pipeline length	1,360,040	37

Missouri River Import Pipeline*							
Scenario A			Categorical Score based on pipe diameter	Scenario B			Categorical Score based on pipe diameter
County	Pipe diameter (inches)	Pipe length (feet)		County	Pipe diameter (inches)	Pipe length (feet)	
Burleigh	40	128,603	3	Burleigh	46	128,603	3
Burleigh	48	74,677	3	Burleigh	54	74,677	2
Kidder	48	168,432	3	Kidder	54	168,432	2
Stutsman	48	83,372	3	Stutsman	54	83,372	2
Stutsman	38	58,345	3	Stutsman	44	58,345	3
Stutsman	46	121,227	3	Stutsman	52	121,227	3
Barnes	46	134,302	3	Barnes	52	134,302	3
Barnes	38	41,756	3	Barnes	44	41,756	3
Barnes	30	77,534	4	Ban	38	77,534	3
Barnes	46	10,000	3	Barnes	52	10,000	3
Cass	46	140,923	3	Cass	52	140,923	3
Cass	30	84,606	4	Cass	38	84,606	3
Cass	32	152877	3	Coss	32	152877	3
Cass	32	60,000	3	Cass	32	60,000	3
Traill	32	158,400	3	Tram	32	158,400	3
Grand Forks	32	81660	3	Grand Forks	32	81660	3

Missouri River Import Pipeline*

	Pipeline Totals	1,576,714	50	Pipeline Totals		1,576,714	45
Lake Ashtabula	Potential storage reservoir	Lake Ashtabula	Potential storage reservoir	Lake Ashtabula	Potential storage reservoir	Lake Ashtabula	Potential storage reservoir

*Both scenarios potentially involve Lake Ashtabula as a potential storage reservoir for treated water (e.g., UV irradiated or filtered via microfiltration system) which may increase risk of biota transfer, although a quantitative estimate of that increased risk largely depends on system actual yet to be fully designed and specified; hence, numeric or categorical estimates of risk are not included in this summary table. Absence from this table acknowledges uncertainty in the magnitude of additional risk associated with reliance on Lake Ashtabula as a storage reservoir, but absence must not be regarded as insignificance.

GDU Water Supply Replacement Pipeline (LAP)							
Scenario A			Categorical Score based on pipe diameter	Scenario B			Categorical Score based on pipe diameter
County	Pipe diameter (inches)	Pipe length (feet)		County	Pipe diameter (inches)	Pipe length (feet)	
Sheridan	88	62,818	2	Sheridan	94	62,818	2
Sheridan	90	51,758	2	Sheridan	98	51,758	2
Wells	90	118,774	2	Wells	98	118774	2
Wells	108	81,338	1	Wells	114	81,338	1
Foster	108	189,552	1	Foster	114	189,552	1
Griggs	108	130,023	1	Griggs	114	130,023	1
Griggs	10	70,006	5	Griggs	8	70006	5
Griggs	26	75,000	4	Griggs	26	75,000	4
Steele	94	20,000	2	Steele	112	20,000	1
Steele	94	15,217	2	Steele	102	15,217	1
Steele	76	95,819	2	Steele	82	95,819	2
Steele	18	94,689	4	Steele	18	94,689	4
Steele	62	100,525	2	Steele	64	100,525	2
Traill	18	10,000	4	Traill	18	10,000	4
Grand Forks	62	67,963	2	Grand Forks	64	67,963	2
Grand Forks	50	56,966	3	Grand Forks	54	56,966	2
Grand Forks	54	123,639	2	Grand Forks	58	123639	2
Grand Forks	34	134,272	3	Grand Forks	36	134,272	3
Grand Forks	26	46,195	4	Grand Forks	28	46,195	4
Grand Forks	18	23,721	4	Grand Forks	20	23,721	4
Polk	24	44,639	4	Polk	26	44,639	4
Walsh	26	115,792	4	Walsh	28	115792	4
Walsh	18	50,000	4	Walsh	20	50,000	4
Cass	76	128,211	2	Cass	82	128,211	2

GDU Water Supply Replacement Pipeline (LAP)

Scenario A			Categorical Score based on pipe diameter	Scenario B			Categorical Score based on pipe diameter
County	Pipe diameter (inches)	Pipe length (feet)		County	Pipe diameter (inches)	Pipe length (feet)	
Cass	34	134,564	3	Cass	36	134,564	3
Cass	72	217,598	2	Cass	78	217,598	2
Cass	38	50,000	3	Cass	40	50,000	3
Cass	14	34,763	5	Cass	16	34,763	5
Clay	38	44,708	3	Clay	40	44,708	3
Ransom	34	90,785	3	Ransom	36	90,785	3
Ransom	14	81,988	5	Ransom	14	81,988	5
Ransom	12	51,456	5	Ransom	12	51,456	5
Sargent	12	23,232	5	Sargent	12	23,232	5
Richland	34	262,944	3	Richland	34	262,944	3
Barnes	24	89,176	4	Barnes	24	89,176	4
Barnes	18	147,311	4	Barnes	18	147,311	4
	Total pipeline length	3,135,442	111		Total pipeline length	3,135,442	108

Reliance on open-water components. USGS (2005a) observed that any water transmission system incorporating an open conveyance (canal or other open channel) would present greater risks for biota transfer than alternative systems relying on closed conveyance (pipeline). If biota treatment failed or achieved only partial success, then open conveyance might allow access to wider environmental settings than a similar breach in a closed-conveyance system that had transmission pipeline terminating at a receiving system's water treatment facility. A similar observation was also noted in USGS (2005b), which considered a preliminary risk-reduction analysis for Action Alternatives outlined in the DEIS (Reclamation 2005b). However, as repeated cautionary notes conditioning this preliminary failure analysis have suggested, an oversimplified interpretation of risks identified from any preliminary analysis—be those risks associated with open-water components or other system attributes related to biota treatment—will likely be accepted or viewed with skepticism, depending on perceptions of acceptable risk.

Differences in water intake and biota treatment as risk factors. Each of the Action Alternatives involving an interbasin water transfer incorporate conventional coagulation-flocculation-sedimentation. While three of four Action Alternatives rely on a wet-slurry pump system for water intake from McClusky Canal, source-water withdrawal directly from the Missouri River (as part of the Missouri River Import Pipeline alternative) relies on bank filtration via radial-collector wells for tapping into source waters, and subsequently realizes additional risk reduction by incorporating pre-treatment options into the system's conceptual design that are consistent with guidance in LT2ESWTR (see §141.717, Pre-filtration treatment toolbox components of the National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) [Federal Register: January 5, 2006 (Volume 71, Number 3)]). From the perspective of overall system performance, however, the prospective role of an open-water component—Lake Ashtabula as a storage reservoir—within the water transmission system may offset these steps toward risk reduction.

The GDU Replacement Water Supply Pipeline Action Alternative incorporates lime softening and microfiltration into the biota treatment regimen, which yields supplemental risk reduction benefits to the overall water transmission system. Yet, as indicated in Figure 7-8 and Table 7-5, and anticipated in USGS (2005b), this Action Alternative's closed conveyance system may present greater long-term risks of unintended biota transfers linked to system failure, especially those failures associated with diminished pipeline integrity, e.g., through pipeline aging or relatively greater risks associated with water loss linked to the system's length and highly varied piping configuration. For example, even from the initial conceptual designs outlined in the

DEIS (Reclamation 2005a), the range of pipe diameters and pipe reaches involving various transitions between pipes and pipe fittings would suggest that pipeline hydraulics may be more critical to long-term performance of this water-distribution-like alternative than the hydraulics of a simple linear pipeline, e.g., GDU Import to Sheyenne River Action Alternative. Again, these differences in system configurations would be better served by an analysis of more fully specified engineering designs, so the role of differing pipeline hydraulics could be more fully appreciated.

UV irradiation, chlorination, and chloramination: A common disinfection process for Action Alternatives. As noted for the universal application of conventional pre-treatment practices in Action Alternatives involved with proposed interbasin water transfers, each also incorporates UV irradiation and chlorination (including chloramination as a process to assure chlorine residues) into their conceptual design of biota treatment as a means of disinfection. Provided these biota-transfer countermeasures are equally implemented across Action Alternatives, risks associated with failures in these features of the biota treatment system would be similar across Action Alternatives. Yet, all Action Alternatives are clearly not equal relative to risks and the role that system failures might play in mediating interbasin biota transfers. For example, in addition to shared countermeasures of conventional pre-treatment regimens (i.e., coagulation-flocculation-sedimentation), UV irradiation, and chlorination-chloramination, the GDU Water Supply Replacement alternative also incorporates lime softening and microfiltration into the biota treatment regimen that would reduce risk. Again, this reduction may be offset by the potential increased risks associated with this Action Alternative’s more extensive pipeline system.

Conceptual systems of choice. While a state-preferred Action Alternative—GDU Import to Sheyenne River—has been identified in the DEIS (Reclamation 2005a), the reliance on open-water features as part of that conceptual design must be considered relative to stakeholder risk tolerance. Differing perceptions of risk will affect acceptance of other alternatives with open-water components in conceptual design (GDU Replacement Water Supply alternative). Yet, if water needs and demands motivate greater specification in engineering design and cost analysis following revision of the DEIS, the preliminary failure analysis considered in this investigation may help identify which engineering tools—be those related to source water withdrawal, biota treatment, or water transmission functions of the system—may contribute to risk minimization criteria that might capture stakeholder support. The current investigation must not be considered an engineering evaluation beyond the technical observations that have considered failure of systems or system components as factors potentially contributing to biota transfers. Engineering costs have not been considered in this study.

Provided the background in USGS (2005a,b), the preliminary failure analysis provides a technical perspective to help focus detailed engineering designs intended to minimize biota transfer risks. For example, the risk reduction benefits of radial-collector well networks and horizontal wells as advanced in the conceptual design for the Missouri River Import alternative are well characterized (Joshi 1991, Fournier 2004) and have been acknowledged by regulatory agencies as tools amenable to reducing risks associated with disinfection-resistant organisms such as *Cryptosporidum* spp. While biota transfer issues are not primarily driven by public health concerns, the technical specifications of LT2ESWTR provide tools capable of addressing, e.g., small-bodied propagules such as disinfection-resistant life stages of fish diseases (such as *M. cerebralis*) and agents of infectious diseases of wildlife that are zoonotic in character (see USGS 2005a). Membrane technologies or media-based filtration options (e.g., sand filtration) might serve revision of DEIS (see SDEIS; Reclamation and Garrison Conservancy [2006]) as tools available for controlling passage of infectious agents in source waters (Duranceau 2001, Mallevialle et al. 1996, Pressdee et al. 2006, Schippers et al. 2004, US EPA 2005a).

Consistent with guiding principles considered in the risk reduction analysis summarized in USGS (2005b), two general attributes of a risk—the spatial attribute, or "where source water will be withdrawn" and the implementation attribute, or "how the water will be delivered" to the Red River Valley—should influence specifications of engineering designs developed consequent to outcomes of the DEIS. Each Action Alternative involving water withdrawal from the Missouri River basin—either at McClusky Canal via wet-sump pump or directly from the Missouri River via radial-collector wells—has considered the spatial attribute critical to reducing risks. Each Action Alternative is equally responsive to this aspect of the spatial attribute, since locations for withdrawal and biota treatment reside in the Missouri River basin, ensuring waters destined for transfer have passed through biota transfer countermeasures intended to reduce risks.

If Action Alternatives involving interbasin water diversions are considered fixed-as-designed—that is, their conceptual designs are carried through to full specification, then built—the resulting water withdrawal, treatment, and transmission system would appreciate reduced risks, but might not be minimized (USGS 2005b). Given the technologies included across all Action Alternatives, risks may be minimized by advancing designs developed as different mixes of the tools currently incorporated into Action Alternatives. Given Reclamation's deferral in selecting an alternative of choice (Reclamation 2005), Action Alternatives presently considered in the DEIS (Reclamation 2005) may be considered a "menu of tools" available to the mission of meeting water needs and demands of the Red River Valley to 2050. Stepwise in the water withdrawal, treatment, and transfer process, the current list of Action Alternatives could be "remixed" to yield a control system that achieves an "on-paper only" risk minimization based on the tools brought forward in the Action Alternatives.

For water withdrawal, the direct tap to the Missouri River via a system of radial-collector wells may afford greater risk reduction than does reliance on wet-sump pump extraction of source waters from McClusky Canal. There are no regulatory benchmarks specific to biota transfers and no promulgated standards specifying acceptable risks related to species invasions. Implementing interbasin water transfers with controls systems proposed in the DEIS would bring to resource management discussions a system of control technologies that are risk reduction tools for managing potential biota transfers. As noted in USGS (2005a), the spectrum of organisms identified as biota of concern display a wide range of life history attributes that may influence choices for risk-reduction tools considered in engineering final design. Given concerns regarding biota transfers throughout the life time of system delivering water to the Red River Valley, system upgrades are anticipated, especially as water treatment technologies mature. As such, biota transfer countermeasures may be maximized by using integrated water treatment technologies currently included in conceptual designs. Costs related to mounting multiple countermeasures would require engineering scrutiny, yet a mix of available technology would yield a control system "as good as you can get." Offsets to these costs might be gained through prospective solutions related to, e.g., pipeline routing.

As characterized in Section 4 and elaborated upon in Section 5 with an evaluation of consequences for "mostly likely affected targets of concern"—Sheyenne River and Lake Ashtabula—water transfer issues go beyond a simple discrimination of "open conveyance" versus "closed conveyance" initially identified in USGS (2005a). Not only how the water is transferred, but what pipeline route and interactions of route selection and system failure should be considered in developing fully specified engineering designs. It should not be surprising, then, that pipeline routing is critical in the risk minimization process that may ultimately reduce risks to acceptable levels. As noted in Section 4, vulnerable habitats are potentially numerous in occurrence; hence, failure risks associated with pipe leaks, breaks, and burst would yield loss-of-water events ranging from releases of likely inconsequential water volumes to releases of large volumes of water, especially if a "worse-case" scenario were realized (e.g., multiple pipe bursts in a relatively limited reach of highly inaccessible region of pipeline coupled with valve and pump control failures that prevented system shutdown). While worse-case scenarios were captured as part of the characterization of risks summarized in USGS (2005a), system failures as contributing or necessary, and sufficient factors linked to biota transfer must be fully detailed before worse-case scenarios can be woven into this failure and consequence analysis. Hence, worse-case scenarios are not considered in this analysis, which focused on conceptual details currently considered (Reclamation 2005a, Reclamation and Garrison Conservancy 2006).

Depending on the final pipeline laid out for the water transmission system, consequences of risks of biota transfers resulting from water treatment or water transmission system failure will vary, e.g., as a function of pipeline location. For example, if pipeline route was determined through the process mapped by ASCE (see, e.g., ASCE 1998), then final selection of designs moved forward to full engineering design could reflect a level of risk tolerance shared by stakeholders. As such, sensitive habitats or otherwise specified exclusion areas could be identified and avoided in pipeline construction. While avoiding issues related to shared rights-of-way (Day et al. 1998), pipeline routes of choice could be designed to parallel existing infrastructure (e.g., public roadways, where habitats have already compromised by past and ongoing disturbance), and provide ample space and geographic links between areas where source waters are withdrawn and treated and areas where product water is targeted for delivery.

Given the conceptual designs included in the DEIS (Reclamation 2005), the risk-reduction tools incorporated in Action Alternatives involving interbasin water transfer provide options that may be considered to yield increased risk reduction in engineering final designs. Risk management options considered in this report would potentially

- impose countermeasures to reduce severity or probability of adverse events occurring,
- segregate or compartmentalize the control system (source-water withdrawal, treatment and transmission) to ensure adverse effects associated with one event would be independent of a second event (e.g., reduce likelihood of cascade failure) potentially manifesting itself as biota transfer linked to loss of receiving system's integrity, or
- transfer risk to other systems (e.g., shift pathways that potentially link biota of concern with habitats of interest to other systems such as disturbance habitats previously compromised by human activity).

Risk avoidance is always an option. However, multiple pathways exists to mediate biota transfers; hence, this default risk strategy may fail within the larger picture, since outcomes associated with competing pathways may yield successful species invasions or shifts in metapopulations (USGS 2005a). Alternatives to risk avoidance are available, and in practice, risks may be reduced with a goal toward risk minimization. A variety of engineering or risk management approaches may eliminate or reduce hazards, prevent initiating events, implement additional safeguards or make safeguards more reliable, reduce adverse effects associated with risk-dependent events or reduce consequences commensurate with risk tolerance of stakeholders. Efforts to reduce or minimize risks can be parsed and considered within the context of their

- efficacy, or "How much of the risk will be eliminated or minimized by the proposed action?
- feasibility, or "Is the proposed action acceptable (e.g., legally, physically, politically, socially, and technically)?
- efficiency, or "Is the proposed action cost-effective, or in other words, is the cost of implementing the action low compared to the loss that could occur if no action were taken?

Integration of Risks of Biota Transfer Conditioned on Control System Failure. Given these generalized and recurring questions common to many resource management issues, informing decision makers through an evaluation of various forms of risks has been, and will continue to be the goal of USGS technical support to resource agencies within DOI. The current investigation illustrates how technical analysis may inform resource managers faced with decision-making in the presence of uncertainty.

A preliminary risk reduction analysis focused on Action Alternatives featuring interbasin water transfers had been completed (USGS 2005b) using a categorical analysis of risks. That preliminary risk reduction analysis suggested that the menu of Action Alternatives in the DEIS (Reclamation 2005a) involvin interbasin water transfers yielded a range in risk reduction—in ascending order, GDU Import to Sheyenne River < GDU Import Pipeline < Missouri River Import to Red River Valley < GDU Water Supply Replacement Pipeline. The preliminary risk reduction analysis noted that similarities in proposed designs for each Action Alternative suggested that each system's risk reduction might provide sufficient margin, depending on system user's risk tolerance. The preliminary risk reduction analysis also observed that greater discrimination among Action Alternatives might be realized in a full design engineering analysis, where, e.g., costs would be captured as part of the design analysis. In fully designed systems, discrimination among Action Alternatives might be increased through greater focus on risks associated with, e.g., routes of transmission pipelines or specific treatment regimens. For example, the reciprocal character of engineering risks were captured in the initial categorical risk reduction analysis, e.g., a high score for risk reduction was assigned to pipeline features characteristic of GDU Water Supply Replacement Pipeline alternative, yet a low score was tendered for risk reduction related by pipeline breaks, since the occurrence of pipe breaks would be greatest in the system designed with most pipeline miles. This assumption also does not discriminate between risks linked to other attributes of a water transmission system such as pipe diameter, which is critical in engineering evaluations that might follow as part of a hydraulic analysis completed for full designs coming from winnowing of Action Alternatives.

Given this context, the categorical analysis of USGS (2005b) was extended to address these pipeline attributes as a function of pipe diameter and pipeline route (considered as linear miles, assuming sensitive habitats were avoided) and dispersion in pipe diameters used in pipeline installation, as indicated by the difference between 90%-tile and 10%-tile (Figure 7-8). Table 7-6 summarizes the updated risk ranking for the Action Alternatives involving interbasin water transfers identified in the DEIS (Reclamation 2005a). As in the preliminary risk reduction analysis (USGS 2005b), each of the Action Alternatives are closely aligned, based on their total risk credits which range between a high of 13 and a low of 11. In contrast to the risk reduction scores derived in the preliminary analysis, the priority ranking of Action Alternatives in ascending order is, GDU Import Pipeline < GDU Import to Sheyenne River = GDU Water Supply Replacement Pipeline < Missouri River Import to Red River Valley. These differences in risk reduction rankings result from the additional attributes linked to pipe diameter and pipeline lengths that have been incorporated into the analysis. In USGS (2005b), a simple category "pipeline" served as the only measure related to conveyance—if treated water was piped, reduced risk was achieved, and the discriminating attribute was pipeline length—and has been elaborated upon in this extended analysis. Two break-outs increasing resolution to "pipeline" were added to the categorical analysis to more fully characterize that simple conveyance attribute—"rank based on median pipe diameter and pipeline length" and "rank based on dispersion (difference between 90%-tile and 10%-tile values)." Preliminary design data summarized in Table 7-6 and in Figure 7-8 provided inputs for this extension of the simple categorical analysis. Median rank score for pipe diameters was 2.0 for GDU Import to Sheyenne River and GDU Import Pipeline, but the former's shorter pipeline length lead to its higher rank score relative. Similarly, Missouri River Import to Red River Valley and GDU Water Supply Replacement Pipeline had median rank score for pipe diameters of 3.0, but the extensive pipeline system of the latter lead to its lower rank score. Measures of dispersion estimated as difference between 10%-tile and 90%-tile (see Figure 7-8) indicate that GDU Water

Table 7-6. Updated risk-reduction credits for Action Alternatives involving an interbasin water diversion (see also USGS 2005b).

Water import alternative	Type of source water withdrawal[1]	Biota treatment plant location[2]	Conventional Pre-treatment[3]			Other treatment proposed[4]				Means of conveyance[5]				Total risk credits[8]
			Coagulation	Flocculation	Sedimentation	UV disinfection	Chlorination-Chloramination	Lime softening	Microfiltration	Open-water	Pipeline	Rank based on median pipe diameter and pipeline length[6]	Rank based on dispersion (10%tile to 90%-tile)[7]	
GDU Import to Sheyenne River	0	1	1	1	1	1	1	0	0	0	[0]	3	3	12 [12]
GDU Import Pipeline	0	1	1	1	1	1	1	0	0	1	[1]	2	1	11 [10]
Missouri River Import to Red River Valley	1	1	1	1	1	1	1	0	0	1	[2]	1	2	13 [11]
GDU Water Supply Replacement Pipeline	0	1	1	1	1	1	1	1	1	1	[3]	0	0	12 [9]

[1] 0=open-water withdrawal; 1=radial collector wells
[2] 0=Red River basin; 1=Missouri River basin
[3] 0=no pre-treatment; 1=pre-treatment
[4] 0=not included in proposed design; 1=included in proposed design
[5] 0=least risk reduction; 3=greatest risk reduction
[6] 0=least risk reduction, 3=greatest risk reduction
[7] 0=least risk reduction, 3 greatest risk reduction
[8] Given the complementary character of the simple category "pipeline" and derivative categories "rank based on median pipe diameter and pipeline length" and "rank based on dispersion (difference between 90%-tile and 10%-tile values)," total risk credits may be adjusted by removing "pipeline" score from total.

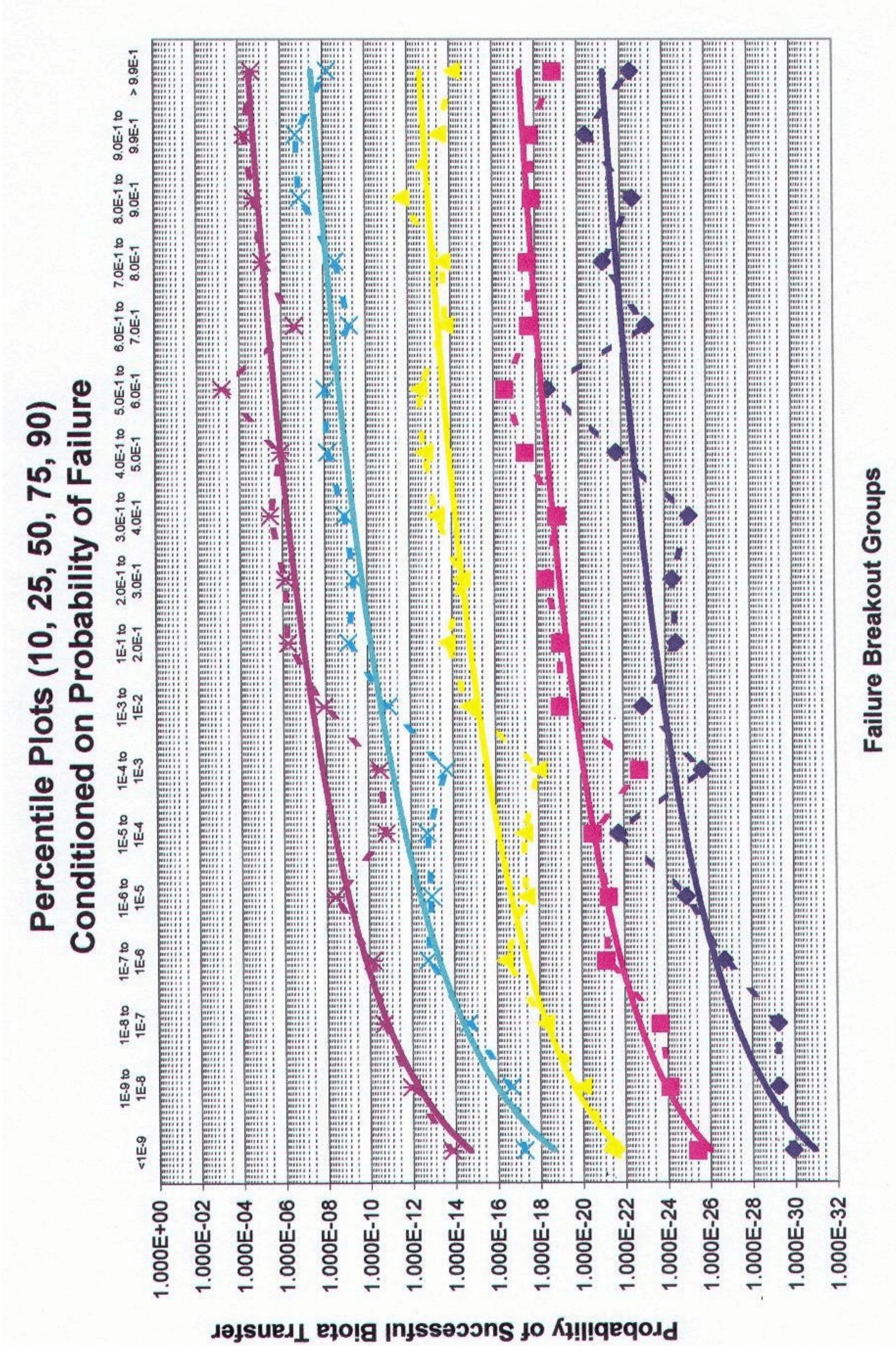
Supply Replacement Pipeline presented greatest dispersion in pipe diameter; hence, the lowest rank score linked to greater hydraulic demands on pipeline structures (see Section 2 for discussion of, e.g., interrelationships of pipe diameter and water flows). Highest risk reduction score (i.e., system displaying least dispersion) was GDU Import to Sheyenne River alternative, which is relatively uniform in pipe diameter throughout its pipeline course.

As evident in this extended risk reduction analysis, depending on category definitions, priority listings of Action Alternatives that involve an interbasin water transfer are relatively more sensitive to pipe and pipeline routing attributes than treatment attributes at this stage of conceptual design. Each alternative shares common starting points for proposed water treatment regimens—sedimentation, flocculation, and coagulation in conjunction with chlorination and chloramination—and once engineering options are detailed with respect to efficacy and costs associated with additional treatment options (e.g., UV disinfection, media or membrane filtration processes, or alternatives yet to be identified such as DAF), an updated risk reduction analysis may be incorporated into engineering analyses. The outcomes for "total risk credits" generated in this extended categorical analysis and summarized in Table 7-6 underscore the importance of interpreting simple arithmetic sums of individual scores within the larger risk picture. For example, the preliminary risk reduction analysis (USGS 2005b) applied a simple measure of risk reduction to the definition of "pipeline," wherein greatest risk reduction was captured by the system conveying treated water in a pipeline throughout its travels in the water transmission system. Consequently, the system having greatest length of pipeline garnered the highest risk reduction score. Yet, as noted in USGS (2005b), regardless of the closed conveyance of treated water throughout its course of transmission yielding greatest risk reduction credits, the pipeline's length also confers risk not fully captured in the preliminary categorical analysis, particularly with respect to prospects of an engineering failure conditioning risks of biota transfer. Hence, the derivative categories "rank based on median pipe diameter and pipeline length" and "rank based on dispersion (difference between 90%-tile and 10%-tile values)" were incorporated into the extended analysis. Given the complementary character of the simple category "pipeline" and derivative categories "rank based on median pipe diameter and pipeline length" and "rank based on dispersion (difference between 90%-tile and 10%-tile values)," total risk credits may be adjusted as indicated in Table 7-6. While GUD Import to Sheyenne River presents a high risk reduction score, risk management may differentially weight component scores in the simple summation process yielding total risk reduction credits. That is, despite having an adjusted total risk reduction score of 12, reliance on Sheyenne River for open conveyance may be a unacceptable condition. Consequently, Missouri River Import to Red River Valley presents the greatest risk reduction (adjusted score of 11), and may be argued as an alternative of interest to further consideration, e.g., in the SDEIS (Reclamation and Garrison Conservancy 2006).

Again, whether considering total risk reduction credits characterized in the preliminary risk reduction analysis (USGS 2005b), or in the extended risk reduction analysis summarized in Table 7-6, summed rank scores are not dramatically different, yet the discrimination evident in these analyses may inform engineering alternatives developed in the future, especially when considered relative to risks of biota transfers conditioned on control system failure. For example, in their simulation study, USGS (2005a) established a framework of risks related to biota transfers potentially resulting from interbasin water diversions. While built upon a generalized analysis based on any biota transfer's "flow-of-events," outputs from a simple-probability simulation captured multiple trials in the flow-of-events characteristic of the transfer or invasion process, which subsequently afforded a probabilistic basis for the ordinal assignment of risks (e.g., very high risk through very low risk) associated with a range of biota of concern (see USGS 2005a). With a preliminary evaluation of the risk-reduction potentials captured by Action Alternatives in the DEIS completed (USGS 2005b) supplemental to the analysis of risks associated with interbasin biota transfer, the current investigation extended that risk-reduction evaluation by addressing control system failure, specifically as that related to failures in water treatment or water transmission systems envisioned as Action Alternatives to accomplish interbasin water diversions (Reclamation 2005a). Figure 7-9 illustrates how risks of biota transfer conditioned on control system failure may inform decision-makers in their engineering design and resource management practices.

Specifically, outputs from the simulation study were reduced using tools of exploratory data analysis (Tukey 1977, Hoaglin et al. 1983), which yielded simple descriptors of the distribution captured by the simulation study. In Figure 7-9, percentile plots (10%-tile, 25%-tile, 50%-tile, 75%-tile, and 90%-tile) for simulation output that characterized risk of biota transfer (USGS 2005a, see Appendix 13) were considered relative to risks charactered for system failure (without specification of type of failure or when failure occurs during service life; see Section 3 of this study). Depending on the risk tolerance of the resource manager, a control system—that is, a water treatment and transmission system—could be designed to meet performance criteria that could be linked to biota transfer. For example, if consensus opinion targeted acceptable risk of biota transfer at 10^{-16}, then risk managers could identify a control system whose risk of failure that might minimize the occurrence of that event. Conversely, if control system failures for a full design system fall out along those values forecast in the current analysis, then the range of biota

Figure 7-9. Percentile plots for risk of biota transfer (90%-tile, purple; 75%-tile, light blue; 50%-tile, yellow; 25%-tile, pink; 10%-tile, dark blue) relative to risks of system failure.


Percentile Plots (10, 25, 50, 75, 90)
Conditioned on Probability of Failure
Probability of Successful Biota Transfer
Failure Breakout Groups
1.000E+00
1.000E-02
1.000E-04
1.000E-06
1.000E-08
1.000E-10
1.000E-12
1.000E-14
1.000E-16
1.000E-18
1.000E-20
1.000E-22
1.000E-24
1.000E-26
1.000E-28
1.000E-30
1.000E-32
<1E-9
1E-9 to 1E-8
1E-8 to 1E-7
1E-7 to 1E-6
1E-6 to 1E-5
1E-5 to 1E-4
1E-4 to 1E-3
1E-3 to 1E-2
1E-1 to 2.0E-1
2.0E-1 to 3.0E-1
3.0E-1 to 4.0E-1
4.0E-1 to 5.0E-1
5.0E-1 to 6.0E-1
6.0E-1 to 7.0E-1
7.0E-1 to 8.0E-1
8.0E-1 to 9.0E-1
9.0E-1 to 9.9E-1
> 9.9E-1

transfer risks could be characterized based on system failures of, e.g., 10^{-4}, 10^{-5}, and 10^{-3}, across the life-time distribution for that system. Needless to say, the preliminary failure analysis completed here will gain resolution as Action Alternatives are eliminated or developed in full design; hence, estimates of system failure will be refined. Similarly, the generalized characterization of biota transfers can reach greater resolution, e.g., if biota-specific transfer risks are characterized, or better yet, if life-attribute-specific risk factors such as body size or UV-resistance may be characterized and considered relative to control system performance.

Despite such an integration of risks to inform resource managers in their decision-making process, risk management questions will always be considered against a backdrop of uncertainty (see USGS 2005a for detail on types of uncertainty). For the current investigations, uncertainties are characterized in Section 7.3, and in particular, those uncertainties that affected risk estimates for control system failure (and subsequently, those failures as initiating events in biota transfers).

7.4 Uncertainties and Risk Management

"Absolute certainty is a privilege of fanatics"

C. J. Keyser
1862-1947
Adrain Professor of Mathematics
Columbia University, New York

Each of the Action Alternatives involving an interbasin water diversion suggest that reduced risk could be achieved by treatment of intake water at the source and transmission via closed conveyance from Missouri River basin to Red River basin (USGS 2005a). However, the extent of risk reduction differs from one Action Alternative to another. To complicate matters, any of the Action Alternatives—be those reliant on within-basin sources of water or interbasin water diversion reliant on source waters from the Missouri River—could be equally foiled by stochastic events resulting in a biota transfer–species invasion process. Conceptual engineering options outlined by Reclamation (2005b,c), however, provide starting points for refined engineering analysis of risks and costs, and continued development of feasibility designs. If an alternative is selected, or if some alternatives are eliminated and others are moved forward in developing resource management plans, then a framework for evaluating the condition of water system components and developing maintenance and operation schedules should be included in long-term management plans, if risks of interbasin biota transfer are to be minimized. These project management needs related to projected long-term use require an evaluation of uncertainties captured by the current Action Alternatives, which is the primary focus of this section and brings closure of this investigation.

7.4.1 Uncertainty related to system failures and biota transfer. Results of the simulation study (USGS 2005) suggested that risks of biota transfers under controlled, closed-conveyance scenario would range from low to very low (estimated at 10^{-6} to 10^{-9} to less than 10^{-9}, respectively, based on simulation outcomes). The range of probabilities in the latter, very-low risk category would reach much lower levels in those scenarios where stochasticity in the biota transfer process was fully captured (USGS 2005a). Low probability-high consequence events likely remain—even under the most controlled engineering practice implemented for an interbasin water transfer including the no-action alternative—but the alternatives considered in this analysis reflect a range of practices available to address the water supply issues of the Red River Valley.

While uncertainty was considered in some detail in USGS (2005a,b), a wide range of sources may be referenced for more comprehensive understanding uncertainty as that relates to environmental and engineering decisions (see, e.g., Ayyub 1998, Halpern 2003, Hammond 1996, Jordaan 2005, Kahneman et al. 1982, Morgan and Henrion 1990, Parsons 2001, Tung and Yen 2005) beyond the scope of this investigation. Aleatory uncertainty—also called random uncertainty or stochastic uncertainty—deals with the predictability of an event, while epistemic uncertainty—also called subjective uncertainty, parameter uncertainty, or state-of-knowledge uncertainty—deals with our state-of-knowledge about a model or portions of a model used in the analysis. Epistemic uncertainty includes both parameter-specific uncertainty and model-specific uncertainty, which are simply different levels of uncertainty embodied within a model. The current discussion of uncertainty will reflect a primary focus on aleatory uncertainty, given its presumptively primary role in mediating failure events that might yield the initial steps in a biota transfer yielding a successful species invasion or shift in metapopulations. Although epistemic uncertainty should be fully incorporated into engineering designs as needed, conclusions reached in this or any other analysis will continually be challenged by our state-of-knowledge uncertainty, which must be considered within the context of acceptable risk. Similarly, unlikely stochastic events, e.g., occurrence of earthquakes potentially yielding infrastructure failures may not be a primary concern of risk managers, e.g., given the prevailing engineering standards and practices in areas of the northern Great Plains of Minnesota, North Dakota, and Manitoba, but interactions between stochastic events and any engineering structures should be also considered within the context of acceptable risks.

In this section, uncertainties captured in the current investigation are considered in two interrelated collections, one reflected by the inherent uncertainties of the conceptual designs presented in the DEIS (Reclamation 2005) and the other related to the materials and installation of infrastructure incorporated into those conceptual designs. The former collection of uncertainties are conveniently viewed through the life time distribution curve, which potentially displays system failures that deviate from the traditional bathtub curve. Not only should design engineers be wary of these uncertainties in life time distributions that influence, e.g., development of maintenance schedules, but stakeholders must be cognizant of limitations in the engineering process that may be entangled with long-term support of infrastructure, e.g., financial support earmarked for operations and maintenance.

7.4.2 Uncertainty associated with traditional concepts of the bathtub curve. As noted in Section 3, the bath tub curve ideally portrays system failure through its life time, wherein early failure rate of a system is relatively high during system initiation followed by a period characterized by a relatively constant failure rate, which subsequently increases late in the system's life cycle. Recall that system reliability may simply be viewed as the reciprocal of failure; hence, system reliability will decrease with age, if it follows the conventional system process. As noted in Section 3 and Appendix 1, Mean Time Between Failure (MTBF) is a frequently applied metric in engineering, especially with respect to discrete components, e.g., motors, pumps, and valves, as well as overall systems such as those multiple-component designs envisioned to met water demands outlined in DEIS (Reclamation 2005).

MTBF considers a system renewed after each failure, then returned to service immediately after failure. For typical distributions characterized by some variance, MTBF only represents a top-level statistic and may not be suitable for predicting detailed time of failure, as uncertainty in failure distributions are inherently variable as a function of time. Simply defined then, MTBF is the average time between failures, and in the present investigation was based on historical data available from existing data compilations or estimated by vendors based on industry experience. Regardless of its data source, MTBF is regarded as a benchmark for reliability, since the measure considered over time can readily identify components or systems that deviate from the value, e.g., present failure rates exceeding MTBF, and appropriate action taken. Where MTBF breaks down is when MTBF estimates are applied without sufficient design specification to identify existing data most pertinent to the estimation process, especially when complex systems are being considered.

While failure estimates applied in the current analysis are sufficient for a preliminary investigation, once full engineering designs are developed, refined estimates of failure rates should be identified and system failures re-evaluated given these focused, empirically-based inputs (e.g., failure rates for specific pumps may be applied to analysis, or specific pipe materials may be incorporated into the analysis, following their design specification). Additionally, depending on final engineering designs, fault-tolerance will be more fully characterized. Specifications of component or system reliability will be better supported by existing data, although fault-tolerant systems tend to be increasingly more complex than non-fault-tolerant systems (see, e.g., Puccia and Levins 1985, Barlow 1998, Blischke and Parbhakar Murthy 2000, Bloom 2006, Cox and Tait 1998, Falk et al. 2006, O'Connor 2002, Rausand and Høyland 2004, Tung et al. 2006). Increased levels of system complexity generally require long-term planning be sufficient with respect to operations and maintenance. System malfunctions may result from one major failure, but may be caused by unexpected interactions involving failures of multiple components, e.g., complex systems whose components are tightly integrated typically fail through the culmination of multiple components failing and interacting in unexpected ways. For example, several component failures—none independently disabling—may interact in unpredictable ways that, when combined, cause system shut malfunction, in part because of the manner in which complex, interactive systems nominally function. Undetected errors in system function (failures that are not observed, e.g., leaks not detected in transmission piping or bearings wear internally with pumps) may occur; that is, failures may be readily observed or latent. Latent failures or incipient failures are more difficult to identify and repair. As control systems enter the full design phase of project development, engineering decisions regarding the level of system complexity required, e.g., to increase fault tolerance, will undoubtedly become an increasingly critical issue of ongoing discussions. Increasing control system complexity, however, does not necessarily imply an increase in a system's integrity throughout its in-service lifetime, and relatively simple water transmission networks may be sufficient to project needs. Complex engineering systems tend to be variously coupled, and the level of system development of the water withdrawal, treatment, and transmission system may be relatively simple, and engineering controls may be developed in direct response to system complexity. Depending on final engineering design for Action Alternative of choice, the level of system complexity (e.g., built-in redundancies to assure system failures are minimized) will undoubtedly reflect uncertainties and their role in maintaining system integrity. Once decisions regarding Action Alternatives of choice are reached, general discussions of system complexity and its role in guiding full designs can be pursued (see, e.g., NRC (2005a), Mays (2005), and Mays (1999) for supplemental background).

Within the context of uncertainty and system performance, risk management practices must be in place, because all systems fail. Recognizing variations characterized by MTBF, various metrics similar to, yet distinct from MTBF have been developed. For example, mean-time-between-critical-failure (MTBCF) discriminates between failures that are relatively benign from an engineering perspective to those failures critical to system function. Mean-time-to-failure (MTTF) is sometimes used instead of MTBF in cases where a system is replaced after a failure, whereas MTBF denotes time between failures where the system is repaired. As such, companion measures to MTBF, e.g., Mean Time to Repair (MTTR), must be considered, e.g., in developing operations and maintenance procedures.

A system's fault tolerance may lead to a false sense of system security, since chances of system failure may be very small at any particular moment, and perceptions of risks will be influenced by differences in an individual's or group's interpretation of categorical or numerical estimates (Miller and Lessard 2000, Morgan and Henrion 1990, Nott 2006, O'Brien 2001, Perrow 1999, Rustem and Howe 2002, Sustein 2002). Equally important are the roles that time and system complexity may play in managing risks. For example, even in the simplest system, time-in-service or other measures of system aging will influence system performance through time; hence, risks of failure are dynamic. Also, as a system's complexity increases, the interdependency of component parts likely increases, which may lead to nonlinear behavior and increased risks of system failures. Risk managers must face a range of scenarios, all linked to the recurring question: "When the system fails, how easy will it be to recover?" For highly fault-tolerant systems, likelihood of failure is less than a standard system lacking redundancy, when they do fail, they can be problematic with respect to their restoration to nominal function. If MTTR is well characterized, especially with those relatively linear systems envisioned in the DEIS (Reclamation 2005), designed fault tolerance may be built in the system to identify components critical to meeting performance criteria, e.g., maintaining biota treatment at prescribed levels of disinfection or removal, and avoiding system down-time that would adversely affect delivery of product water to meet demand.

Although widely applied and having a long history in reliability analysis, MTBF should be considered within the context of its inherent shortcomings relative to uncertainty. Component MTBFs are compiled in databases that are heterogeneous collections of failure data (e.g., across many different manufacturers, components with similar functions but having different designs and performance specifications), which contribute to inaccuracies and widely divergent values that are poorly captured by estimates of central tendency. In part, reliance on MTBF has led to the negative exponential distribution being applied frequently to failure analysis, which may yield an unknown bias to forecasts projected for a typical life time distribution. Once engineering systems are more fully designed, however, these shortcomings may be addressed, and uncertainty should be less than experienced in preliminary analysis. Also, while MTBF has been increasingly considered an "acceptable" level of failure, often linked to identifying root-cause of a failure, such engineering practice is being reconsidered through alternative measures, e.g., Maintenance Free Operating Period (MFOP), that are being developed (see, e.g., Kumar et al. 2000, Todinov 2005). While these measures are currently not fully supported in all engineering practices, depending on the project's timeline, these alternatives may be applicable to Action Alternatives advanced to full design.

Life time distribution and hazard function. MTBF assumes that the failure rate is constant for all intervals, yet the failure rate of a system more likely varies with time. By calculating the failure rate for smaller and smaller intervals of time, Δt, the interval becomes infinitely small and yields a hazard function which is the instantaneous failure rate at any point in time,

$$h(t) = \lim_{\triangle t \to 0} \frac{R(t) - R(t + \triangle t)}{\triangle t \cdot R(t)}$$

or,

$$h(t) = \frac{f(t)}{R(t)} \quad .$$

If the hazard function is constant, then the failure rate is the same for any equal period of time, which implies that failures occur with equal frequency during any equal period of time. While the exponential failure distribution has a constant failure rate, the Weibull distribution may be characterized by a hazard function that is not constant, but varies with time. Regardless of which distribution is incorporated into any preliminary analysis, uncertainties in any forecasts will be unavoidable. A life distribution is simply a collection of time-to-failure data, or life data, graphically presented as a plot of the number of failures versus time. Failure data compiled through existing data sources are similar to any statistical distribution, but input values are life data that are necessarily time dependent. Data quality and quantity issues are not unlike those encountered in analyses developed from data mining activities, e.g., Bessler et al. (2001), Dansu and Johnson (2003), Vazirgiannis et al. (2003).

The typical bath tub curve considers all possible failure mechanisms that the population will encounter. Some failure mechanisms may occur more frequently in the early life phase, while others will be more common in the steady-state or wear-out phases. Most often, life distributions are characterized by the normal distribution, the exponential distribution, the lognormal distribution, or the Weibull distribution. Different failure mechanisms will yield time-to-failure data that fit different life distributions, which should be reiterated from this preliminary analysis, once system design is fully specified. As a source of uncertainty in the current analysis, selection of life distribution may be addressed in a sensitivity analysis that must be developed under specification of a full system design. The illustrative forecast in the current study was based on Weibull analysis, with early failure phase essentially pacing a negative exponential. Assumptions of other life distributions may be employed by stakeholders as they consider various alternatives currently envisioned in the DEIS (Reclamation 2005) or others yet to be identified (see SDEIS 2006).

For example, in contrast to the Weibull analysis to forecast output in the current investigation, normally distributed failure data may be incorporated into reiterative analyses, wherein a symmetric "bell-shaped" curve characterized by mean, median, and mode may be brought to the analysis (Figure 7-10). Failure rate of a normal life distribution increases monotonically with time, which is a pattern exhibited by failures due to wear-out. While that assumption was not made in the output generated in this analysis, following that lead may serve to "smooth" the transition from steady failure rate to increasing failure rate typical of life time distributions encountered in aging systems. Normal distributions may also be applied to systems wherein additive effects of random variables are anticipated, e.g., for mechanical system failures that occur as a result of the accumulation of small and random mechanical damage, which again may be a function of system age. Although normal distributions are commonly understood by a stakeholders, their application under incompletely specified conditions may be a source of greater uncertainty than those captured by exponential and Weibull distributions (see, e.g., Whitaker and Robinson 1967, Haight 1967, Patel and Read 1982, Evans et al. 2000, Balakrishnan and Nevzorov, 2003, Pal et al. 2006), and the interrelationship of these distributions may be incorporated into engineering-specified failure analysis, e.g., where a wear-out phase may be modeled by a normal life distribution derived from component-specific empirical data.

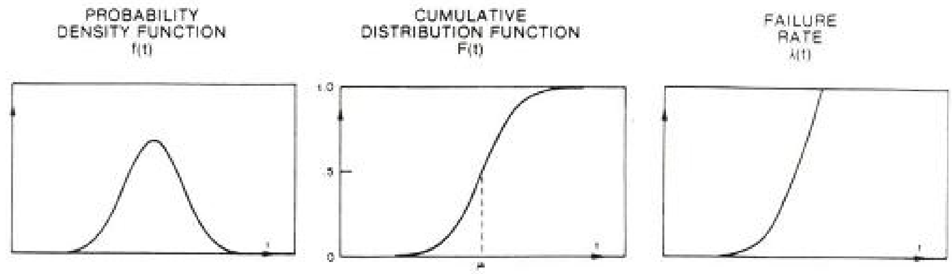


Figure 7-10. The probability density function or f(t), the cumulative distribution function or F(t), and failure rate λ(t) of a normal life distribution (see, e.g., Patel and Read 1982).

In contrast to the normal distribution, an exponential life distribution is characterized by a constant failure rate (Figure 7-11), and is frequently applied to the analysis of failures in the steady-state phase of the bath tub curve. Again, the relationship between exponential and Weibull functions reinforce the strengths of opting for these distributions in this initial analysis of failures as conditions linked to biota transfers potentially associated with interbasin water transfers.

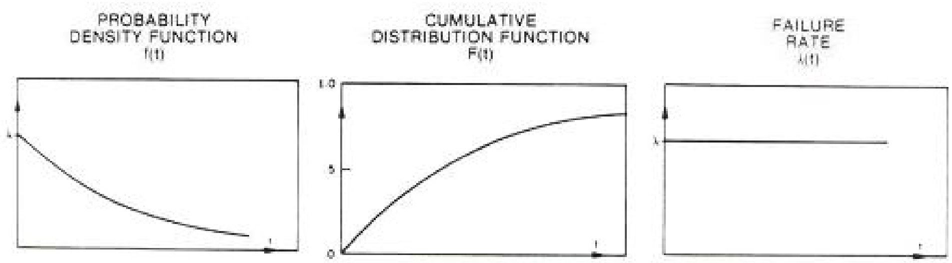


Figure 7-11. The probability density function or f(t), the cumulative distribution function or F(t), and failure rate λ(t) of an exponential life distribution (see, e.g., Pal et al. 2006).

As an alternative assumption that could have been selected for the preliminary failure analysis of this investigation, the lognormal life time distribution is simply one wherein the natural logarithms of the lifetime data, ln(t), form a normal distribution. As such, a data transformation yields a distribution characterized life data will form a straight line when plotted on a lognormal plot (Figure 7-12).

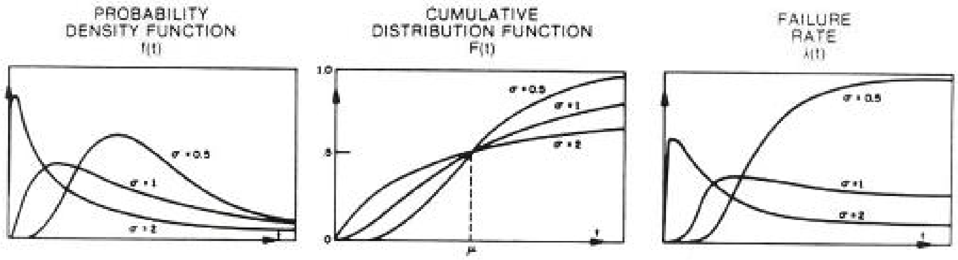


Figure 7-12. The probability density function or f(t), the cumulative distribution function or F(t), and failure rate λ(t) of a lognormal life distribution (see, e.g., Evans et al. 2000, Balakrishnan and Nevzorov 2003).

The failure rate curve of a lognormal life distribution starts at zero, rises to a peak, then asymptotically approaches zero again for all values. Most often, the lognormal distribution results from the multiplicative effects of random variables. Such interactions are encountered in many natural processes which makes it a viable option for reiterative analysis, if stakeholders choice to pursue those options as they consider Action Alternatives or full engineering designs.

Weibull life distribution was initially developed to investigate metal fatigue failures, which encouraged its application in the current investigation (see, e.g., Abernethy 2000, Murthy et al. 2004, Reliasoft 2005a for details on Weibull analysis; Figure 7-13). As noted in Section 2 and Appendix 1, Weibull distribution is described by scale, shape, and location parameters, and is similar to the lognormal distribution. However, two differences between them potentially influence outcomes linked to assumptions use in any analysis: (1) the Weibull distribution's probability density function does not start from zero and (2) the Weibull distribution's failure rate λ monotonically increases for shape factor, β > 1 and monotonically decreases for β < 1.

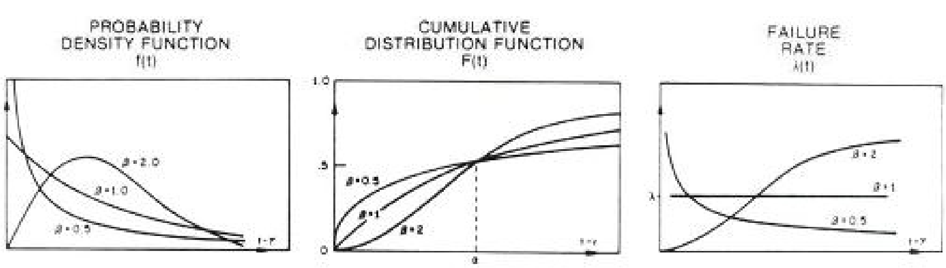


Figure 7-13. The probability density function or f(t), the cumulative distribution function or F(t), and failure rate λ(t) of a Weibull life distribution (see Abernethy 2000, Murthy et al. 2004).

The Weibull distribution is robust and can take on many shapes, depending on input values that capture all the phases of the bath tub curve, as was done in this preliminary analysis (see Table 3-10). As in the current study, Weibull distribution is usually an initial model of choice in reliability engineering, in part because of its relatively simple mathematics, flexibility, and empirical findings that indicate it fits failure mechanisms commonly encountered (e.g., due to metal fatigure). However, once additional engineering designs are available for Action Alternatives, alternative life time distributions such as the lognormal distribution may prove sufficient to reiterative analysis, since it may be more representative of the physical phenomena governing system performance.

Alternative life time distributions. Simply stated, reliability is the probability of a component or system performing as intended for some period of time under specified operating conditions. Typically, reliability is graphically captured by the bath tub curve (see Section 2 and Appendix 1), yet ample observation suggests the typical distribution need not always be characteristic of all systems. For example, alternative estimates of failure rate functions may indicate life distributions far from the typical bath tub curve (Figure 7-14 and Figure 7-15). Depending on the system, its design and build, both figures illustrate life time distributions potentially observed, e.g., for an interbasin water withdrawal, treatment, and transmission system. Figure 7-14 and Figure 7-15 both present a decreasing failure rate early in life largely linked to the start up process, handling or installation defects, then each characteristically presents a constant failure rate reflecting the system's inherent reliability. Each hypothetical system then enters the transition to wear-out phase differently, e.g., because of differences in operations and maintenance practices. Figure 7-14 displays increasing failure rate as the system enters wear-out, then returns to a decreasing failure rate associated with, e.g., a delayed maintanence operation or repair necessitated by component failure.

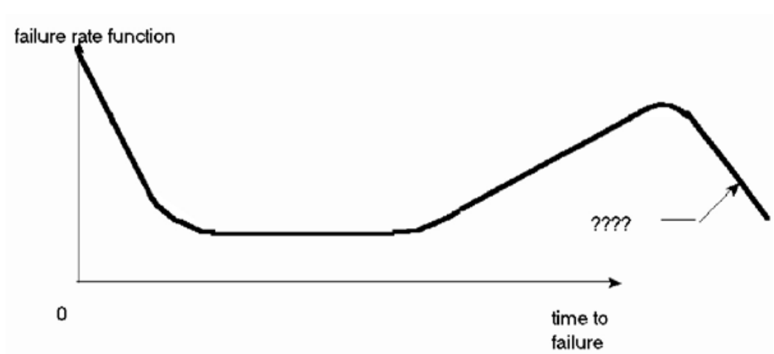


Figure 7-14. The bathtub curve with typical wear-out phase, e.g., displayed in systems having delayed maintenance schedules (from L. George, American Society for Quality at http://www.asq.org/).

In contrast, a similar early-life and steady-state (constant failure rate) period may be displayed by a system, as illustrated in Figure 7-15, but because of differences in maintenance practices (e.g., regular maintenance schedule *v.* condition-based maintennance practices) failure rates do not enter the typical wear-out phase of system life, e.g., failure rates do not increase or ideally, continue to decrease with time.

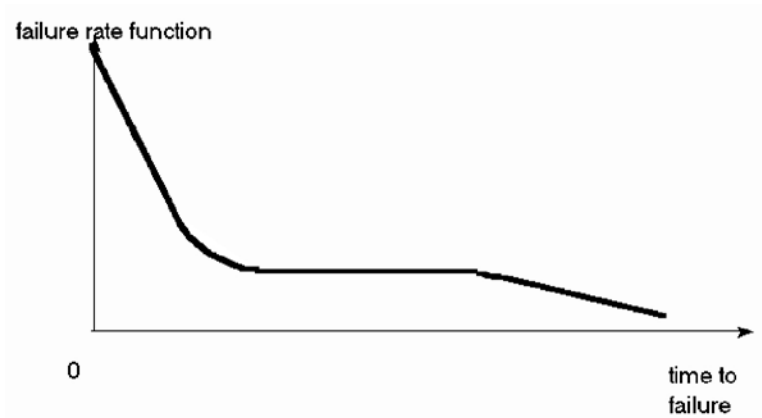


Figure 7-15. Typical bath tub wear-out phase is not observed because repair and replacement schedules include retirement prior to increased failure rates characteristic of wear-out phase (from L. George, American Society for Quality at http://www.asq.org/).

Both failure rate functions depicted in Figure 7-14 and Figure 7-15 illustrate the value of component retirement in maintaining system performance, where the system in Figure 7-14 experiences decreased performance owing to delayed retirement, and the system in Figure 7-15 experiences enhanced performance linked to retirement prior to initiation of wear-out phase. Depending on engineering and risk management practices that support the system of interest, either life time distribution may be acceptable, e.g., early retirement means fewer operating hours per component per time which will have an associated unit cost, while retirement initiated upon observation of increased failures in the system may be acceptable, given the risk tolerance specified for the system.

While these are but two of the possible alternatives potentially associated with a control system comprised of modules targeted on system functions—water withdrawal, water treatment, and water transmission—the preliminary failure analysis of Section 3 includes an outcome typical of a non-repairable system, which in part reflects the conservatism reflected by stakeholder concerns voiced throughout the course of this technical support activity. Rather than enter a reiterative analysis based on conceptual designs captured in the DEIS (Reclamation 2005), stakeholders working with Reclamation can evaluate both within-basin and interbasin alternatives collaboratively, as the panarchy process of NEPA unfolds in the near and distant future.

7.4.3 Uncertainties associated with control system, its infrastructure materials and installation. While numerous components will necessarily be specified and incorporated into a control system as a full design matures, for this preliminary failure analysis the greatest uncertainties are captured by the system and its components—water treatment and transmission modules—most likely critical to mediating biota release in the event of failure. Narrative discussions of uncertainties associated with conceptual system designs identified in the DEIS (Reclamation 2005a) and their interactions with environments (internal and external) that would influence their performance will be considered in the following sections.

Uncertainties associated with control system. In contrast to the analysis of risks associated with biota transfer derived from a simulation completed in USGS (2005a)[2] where categorical assignments of risk ranged across very low, low, moderate, high, and very high groups, the preliminary failure analysis for the conceptual engineering designs identified in DEIS (Reclamation 2005) relied on a single presumptive life time distribution for the control system (see Section 3). That life time distribution also reflected random system behaviors bounded by empirical limits suggested from government and industry data compilations or conceptual limits linked to presumptive regulatory values generalized, e.g., as extensions to benchmarks included in LT2ESWTR for protection from disinfectant resistant organisms such as *Cryptosporidium* spp. (see USGS 2005a, particularly Appendix 10 correspondence with Whirling Disease Foundation regarding efficacy of microfiltration in controlling *M. cerebralis* life stages mostly likely to occur in fish hatchery discharges). Hence, a presumptive bound to system performance may rely on benchmark value linked directly to public health concern yet confer sufficient margin of safety for concerns related, e.g., to fish health. The 30-day moving average plotted on Figure 3-10 then captured the trends anticipated for that simple life time distribution over a 10,000-day service period. As noted earlier, alternative life time distributions are potentially of interest to stakeholders and should be considered when full design specification is available to, e.g., develop a reliability-based maintenance program.

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[2] Biota transfers were considered as a series of independent events depicted through a simple fault-probability tree evaluated through more than 1,700 iterations, then categorized with respect to transfer risk conditioned on system performance.

Beyond the issue of presumptive life time distribution, even relatively simple systems present a range of uncertainties, which stem from performance of system components as well as interactions among components. System attributes manifested by component interactions in and of themselves may contribute to system failure, or perhaps serve as a primary factor leading to a system's loss of integrity and failure to perform as intended. Because system failure potentially involves factors linked to interaction among components as well as the components themselves, uncertainty associated with systems go beyond a simple analysis of individual components. Hence, a preliminary analysis of system failure and the role failure potentially plays in biota transfers must rely on tools such as root-cause analysis and failure-mode and effects analysis (FMEA). A fully implemented application of these tools in the current investigation would have been premature, given the unavoidable under specification of conceptual designs. Yet, these tools should be incorporated into future analyses where FMEA completed within a HACCP process may help refine failure analysis in parallel with future engineering designs.

Root-cause analysis is generally regarded as a tool applied to retrospective studies; that is, root-cause analysis identifies the basic source or origin of system problems through a step-by-step approach that leads to the identification of a fault's initiating event. As a predictive tool, root-cause analysis is critical to full designs of any water transfer system—regardless of whether it involves within-basin or interbasin source—since past performance of other systems may influence the design more fully developed to address Red River Valley water needs and demands. System or component failures happen for a reason and a specific succession of events lead to a failure. Root-cause analysis follows the cause-effect path from the final failure back to the root cause which may be applied to scenario development targeted to support of a fully specified engineering design. For example, by evaluating other water system failures in retrospect—either in supporting scenarios or actual occurrences—faults can be identified as contributing and non-contributing factors that caused a failure event such as biota transfer. Root-cause analysis provides a method for investigating, categorizing, and eliminating, root-causes of incidents in new builds by addressing consequences linked to quality, reliability, and manufacturing processes.

Although initially considered as one of the tools applicable to this preliminary failure analysis, deferring FMEA to a future iteration of engineering design was indicated, given the intent of conceptual designs included in the DEIS (Reclamation 2005a). FMEA is a flexible tool, easily imported into a HACCP process, and has been variously adapted for many different purposes. Given the anticipated outcomes of the NEPA process, and recognizing the DEIS identified that Reclamation presently had not preferred Action Alternative, FMEA could be incorporated into future work following its usual implementation to improve designs for processes, and subsequently, help identify a system with reliability sufficient to attain performance standards through improved quality and increased safety which, in part, attends to stakeholder input. Collateral to these gains, the full-design system would likely yield optimized costs and potentially increase stakeholder satisfaction in a consensus-building effort. The tool can also be used to establish and optimize maintenance plans for repairable systems and guide development of control plans and other quality assurance procedures. As frequently implemented, FMEA also provides a knowledge base of failure modes and corrective actions that can be used as a resource in future troubleshooting and mitigation efforts.

In the full-design phase of the Red River Valley water supply project, FMEA could enable potential errors or faults to be predicted during the early design stages by providing a structured approach to the analysis of root-causes of failure, the estimation of severity or impacts of those failures, and the effectiveness of strategies for prevention. Simply stated, FMEA helps identify:

- what could wrong,
- how badly it might go wrong, and
- what needs to be done to prevent or mitigate the problem.

By identifying early in the development cycle where actions to overcome these issues may be incorporated into the design process, solutions may be identified that enhance system reliability. In contrast to the generalized failure modes employed in this preliminary failure analysis (e.g., a pump fails, a pipe breaks), FMEA may be used to identify failure modes linked to specific components, and corrective actions to mitigate the failures may be formulated.

FMEA becomes even more critical in systems such as the Action Alternatives identified in the DEIS (Reclamation 2005) wherein competing failure modes are likely to exist. For example, the FMEA process may view the conceptual designs as systems-in-series, yet develop an understanding of relationships among different competing failures modes (e.g., does pipe break occur near joints or some distant from joint, does membrane performance vary seasonally) that leads to developing and maintaining a more reliable system. Interactions among system components as well as interactions between the system and the environment (e.g., how does frost heave of soil potentially affect pipeline performance) can be more complex than system construction. Elaborating on outcomes forecast in this preliminary failure analysis could directly support FMEA in future engineering design efforts. For example, fault tolerance is an essential attribute for achieving high reliability in water distribution and control systems. As with any reliability analysis, the starting point require understanding key components and subsystems of the system and their required functions. In a fault tolerant system, it is important to understand the contribution of each module—source water withdrawal, water treatment, and water transmission—to the system's reliability.

Reliability is an integral part of any water withdrawal, treatment, and transmission system layout, design, operation and maintenance. Over the past 10 to 20 years, reliability of water transmission and distribution systems has received increasing attention, yet there remains no commonly applied tool available for reliability assessment. The simple process followed in completing this preliminary failure analysis focused on conceptual designs for Action Alternatives, and found common attributes across those involving interbasin water diversions that were sufficient to complement a comparative risk reduction analysis reported in USGS (2005b). Depending on future reiterations of the failure analysis, particularly as systems become more complete in design, fully integrated flow-based hydraulic and failure analysis models may be applied to the evaluation process. Alternatively, recent publications by AWWA (Kleiner et al. 2005) focused on risk management of large-diameter water transmission mains illustrate a method to interpret system indicators to evaluate condition water transmission mains. As indicated by this and similar studies (see, e.g., Marshall 1999, Kleiner et al. 2004a, Reed et al. 2004), low rates of failure combined with the high costs of inspection and condition assessment are the main reasons behind the relative paucity of empirical data regarding the condition of large-diameter buried pipes. Managing failure risk requires a deterioration model to forecast asset condition as well as its possibility of failure, which will be critical to a comprehensive evaluation of failures potentially linked to biota transfers for the final build derived from the initial evaluations of Action Alternatives previewed in the DEIS (Reclamation 2005). Effective management of failure risk of large-diameter water transmission mains requires knowledge of current condition, rates of deterioration, expected consequences of failure, and the operator's risk tolerance.

Companion to these efforts to address uncertainty associated with system reliability and to forecast failure in large-diameter water transmission pipelines, AWWA (Reed et al. 2004) also recognized the value of developing techniques for monitoring structural behavior of pipeline systems. Here, investigations were undertaken to identify techniques to monitor the structural integrity of water supply systems, particularly those having diameters of 30 inches or greater or considered operationally critical. To address uncertainties reflected in the current failure analysis, critical parameters for system monitoring may be identified for the range of pipe materials targeted for inclusion in full engineering designs. At present, evaluation of structural capability of large diameter pipelines relies on a combination of structural analysis, statistics, and limited measurements of pipe-wall condition. As noted in this and other studies focused on water treatment and water transmission system reliability, these measures may not fully capture the temporal variability characteristic of the system, its structural behavior, or operations. Real-time monitoring will likely be critical to attaining performance goals established for Action Alternative of choice for meeting Red River Valley water demands, and could be developed in conjunction with full engineering designs for the system. AWWA (see, e.g., AWWA 2003a, Reed et al. 2004, Kleiner et al. 2005) recognized that no single technique could meet all of requirements for pipeline structural monitoring; hence, different combinations of techniques were identified that might be appropriate under various circumstances. For example, monitoring parameters were classified into one of three groups: global monitoring parameters (internal pressure, external pipe load, wall thickness), local monitoring parameters (leakage rates, crack growth, joint integrity), or environmental monitoring parameters (soil resistivity and pH levels, water pH and temperature), which in combination would assure a minimal supporting data compilation sufficient to the task of full engineering design and development of long-term maintenance and operation plans.

Uncertainties captured by biota treatment and water transmission pipeline. As noted in Section 3, water withdrawal, treatment, and transmission systems involve a variety of modules, e.g., water intake from surface water or groundwater sources, pumping stations, storage reservoirs, and piping with associated fittings. Each of these modules or components may be further divided into components and sub-components, all capable of failure independent of one another or as a result of a failure linked to their interaction (see, e.g., Cesario 1995 , Griggs 2005). For example, pumping stations consist of structural, electrical, piping, and pumping unit sub-components, with the pumping unit further sub-divided into pump, driver, controls, and power transmission units. Characterization of sub-components varies on the level of detail required for analysis as well as the level of detail of available data, which will ideally match the hierarchy of building blocks used to construct the water withdrawal, treatment, and transmission system. As such, uncertainties associated with these system components influence this preliminary failure analysis, and set the agenda for the reiterative approach practiced in risk analysis.

For example, Section 3 merely summarized failure rates, e.g., for a variety of components such as pumps and valves, with no specification given as to their position within a full-build system. Granted, a water transmission system operates as a system of independent components with the hydraulics of each component being relatively straightforward, e.g., fluid flow through pipes is relatively simple as noted in the brief overview in Section 3. However, these components depend directly upon each other and influence each other's performance, including interactions that may yield a fault that results in system failure. Uncertainties associated with this aspect of the preliminary failure analysis should be easily addressed, as the initial set of conceptual designs is winnowed and subsequently developed in a detailed engineering design and analysis. Then, the preliminary failure analysis can be refined through reiteration to include, not only greater detail of components, but also an evaluation of how the systems will perform hydraulically under various demands and operating conditions. A fully integrated hydraulic analysis of a full-design system, including water withdrawal, treatment, and transmission components, will be capable of greater resolution in forecasting system failures related to, e.g., pipe breaks, leakage, valve failure, and pump failure (see, e.g., Mays 1989, 2000, 2002, 2004a).

Water treatment is a critical function of the system envisioned for meeting the water needs and demands of the Red River Valley. As noted in USGS (2005b) and throughout the water resource's literature (see, e.g., Haas 1999 and references cited therein), water disinfection—whether targeted by conventional public-health related concerns associated with drinking water or targeted on concerns related to risks associated with biota transfers consequent to interbasin water diversions—generally occurs as a two-step process wherein (1) particulate matter is removed by conventional treatment to reduce turbidity in source waters and thus, reduce "habitat" for viruses and bacteria adsorbed to particulate material, and then (2) pathogenic microorganisms are inactivated by chemical treatments (such as chlorination and chloramination), physicochemical treatments (such as UV disinfection), or removed through physical treatments (such as membrane filtration; see, e.g., Letterman 1999 for overview of water treatment process; see also Mallevialle et al 1996, Duranceau 2001, Schippers et al 2004 for discussions of membrane systems). Combined water treatment technologies may be applied to the water disinfection process, although each step in the water treatment process will be characterized by uncertainties. In this preliminary failure analysis these uncertainties are linked to estimates of performance benchmarked on available regulatory guidance, which assumes those indicators sufficiently attend to uncertainties reflected by biota transfer issues.

For example, target organisms such as *Cryptosporidium* spp. served as preliminary indicators of system performance and provided initial support in an analysis focused on wider concerns related to biota transfer. For disinfection-resistant agents such as *Cryptosporidium* spp. and similar sized organisms, filtration provides an alternative method of treatment through removal, which may be used singly or in conjunction with other treatment technologies (see, e.g., Schippers et al 2004, Duranceau 2001, Mallevialle et al 1996). Similarly, UV irradiation may provide sufficient inactivation to satisfy water treatment objectives, since treatment may not be sufficient to address risks associated with chlorine-resistant life stages. Adequate filtration or alternative treatments may attain those performance criteria and provide protection from organisms whose life histories suggest such treatment methods would be capable of achieving the level of disinfection or inactivation specified. The strength of combined disinfection and inactivation technologies may provide treatment of, e.g., *Cryptosporidium* and other protozoan, bacterial, and viral agents of waterborne disease sufficient to meet stakeholder concerns related to biota transfer (see, e.g., Percival et al 2004, White 1999, Letterman 1999, Schippers et al 2004). Both UV disinfection and membrane filtration have been incorporated into conceptual designs considered in the DEIS (Recalamtion 2005), and once the final list of full-design systems has been identified, the uncertainties associated with these treatment technologies will track the potentially unlimited number of virtual systems conjured up in any preliminary failure analysis.

Regardless of the water treatment modules configuration in a full design, water transported through the transmission system will not be sterile; hence, even in the final engineering design, uncertainties will be present that will necessarily influence how system failure will be perceived relative to its role in achieving biota transfer. Although treated waters will be relatively free of organisms, product water entering the transmission module from the water treatment module will contain organisms that survive the treatment process (e.g., recovering from UV treatment will occur, body size was less than size exclusion limit, or short-circuiting occurred in an otherwise normally functioning membrane unit; see Schippers et al. 2004). Also, organisms may enter the transmission system through the pipe network, a circumstance more likely to occur with system aging. A variety of pathways are available to organisms and enable their entry into the water transmission system following treatment, including treatment breakthrough or short-circuiting, leaking pipes, valves, joints, and seals, recolonization of water storage reservoirs, and inadequate system security among others. A steady, although intended to be low, influx of bacteria, fungi, protozoa, algae, nematodes, and other microorganisms may enter any transmission and distribution system (Sibille et al., 1998), and their origins may be through the source water (even though it has passed through a biota treatment module) or at any point within the transmission system following output from the treatment unit. Treated water encounters numerous possibilities for recontamination, e.g., based on the system's construction, operation, and maintenance (see, e.g., Berger et al. 1993, EPA 2004d, AWWA 2006a). Consequently, regardless of their source, these organisms will enter the transmission system, attach to pipe walls, and become part of a biofilm (see, e.g., LeChevallier 1999, Berger et al. 1993), which is a complex mixture of organisms, organic, and inorganic material accumulated within a microbial-produced organic matrix attached to the inner surface of piping, generally as patchy accumulations whose establishment initially reflects hydraulic "habitats" amenable to colonization (see, e.g., van der Wende and Characklis 1990, Abernathy and Camper 1997, LeChevallier 1999a, Doggett 2000).

Other sources of uncertainty related to colonization of the transmission system are numerous. For example, regrowth events may occur, e.g., any growth that occurs in the water-system network, most often as a result of recovery and growth of environmentally- or disinfectant-stressed microorganisms. An organism's survival in water transmission and distribution systems varies, e.g., with their ability to grow and produce biofilms. These organisms will range in their pathogenicity, and include biota of concern considered in USGS (2005a) as well as numerous species that present similar life histories. Formation of biofilms may increase pipe corrosion, as indicated in Section 3, and MIC—microbially-induced corrosion—may adversely affect pipe hydraulics and reduce water quality through increased microbial populations within biofilms. Broad classes of organisms and toxins potentially of concern, and that should be considered within the context of system failures upon reiterative analysis completed in parallel of full designs completed under detailed engineering specification include viruses, bacteria, fungi, protozoa, invertebrates, algae and algal toxins, and microbial toxins which in part were incorporated into the initial evaluation of biota transfer risks considered in USGS (2005a). For a more complete treatment of sources of uncertainty linked to microbial communities and biofilms as sources of biota transfers potentially viewed as derivatives of system failure see, e.g., Marshall 1992, LeChevallier 1999a.

Uncertainties associated with infrastructure materials and installation. Given conceptual designs in the DEIS (Reclamation 2005a), materials for pipeline construction include DIP of several standard thicknesses to handle different pressure loads, as well as ST pipe and PVC pipe as outlined as optional materials used in conceptual designs identified in the DEIS (Reclamation 2005). For buried pipe, gasketed joints are commonly used, e.g., for ductile iron, welded steel, and PVC pipe, to provide a range of flexibility which reduces breaks associated with earth movements such as settling or creep. PVC pipe is increasing found in transmission networks, since the material has good hydraulic characteristics and is corrosion resistant. Incorporation of PVC pipe into the full engineering design would reduce uncertainties associated with pipeline failures; PVC pipe consistently exhibits the lowest failure rates of all pipe currently in service, as noted in Section 3 and references therein. However, at present PVC pipe is capacity-limited (pressure-limited) and must be considered as one of various pipe materials used, if required in a full engineering design where applicable (see Nayyer 2000, Moser 2001 and standards and references cited therein).

Materials used in any water-transmission system's construction, and its operation and maintenance afford ample sources of uncertainty with respect to potential system failures linked to biota transfers. For example, types of pipe—DIP, ST pipe, and PVC pipe—and various appurtenances—valves, joints, and fittings—vary with respect to their vulnerabilities to developing biofilms. And, these variations across pipe and appurtenances will be influenced by the quality of product water being transferred. For example, pipe materials may be more influenced by levels of organic matter in the system (see, e.g., Volk and LeChevallier 1999), since some materials provide better habitat for growth—bacterial levels on iron pipes generally exceed those on PVC pipes (Norton and LeChevallier, 2000). Biofilms also develop more rapidly on iron pipes, even with corrosion control (Haas et al., 1983; Camper, 1996), and iron pipes support a more diverse microflora compared to PVC pipes (see, e.g., LeChevallier 1999a). Tuberculation of iron pipes (see Section 3) also affects biofilm development, especially as systems relying on iron pipe age (Geldreich 1996). Materials that support microbial growth include rubber, silicon, PVC, polyethylene and bituminous coatings (Schoenen and Scholer, 1985; Frensch et al., 1987; Schoenen and Wehse, 1988), and lining materials (e.g., to control internal corrosion) may contain additives, solvents, or monomers capable of supporting microbial growth (Rigal and Danjou, 1999). Corrosion can occur internal or external to the pipe, and is variously affect by product-water chemistry, presence of iron and sulfur-oxidizing bacteria for internal corrosion, and the soil corrosivity, water table, and electrical grounding for external corrosion (see Section 3). And, as systems age corrosion increasingly becomes a risk factor to address in operations and maintenance of the system, especially as corrosion contributes to or is directly linked to leaks in pipelines, valves, joints and seals. These individually or jointly may yield pipe breaks or bursts critical to enabling the biota transfer process.

Long-term operation of the water withdrawal, treatment, and transmission system is also a source of numerous uncertainties the preclude a definitive estimate of system failures adversely linked to biota transfer. As Section 3 briefly noted, transmission system hydraulics is critical to operations yielding a system that meets performance criteria targeted on meeting stakeholder concerns related to biota transfer. Hydraulic characteristics will influence system integrity, especially as that relates to, e.g., organic matter (such as DOC) that influences biological activity of biofilms developing within the system through time (see, e.g., Volk and LeChevallier 1999).

For example, flow rates—system-wide or localized, e.g., system dead ends or near appurtenances—influence growth and survival of microbial communities characteristic of biofilms, so system attributes related to pipe configuration, material, condition and size, water demand, pump operation, and elevations must be viewed in the preliminary failure analysis as uncertainties that should be addressed in subsequent discussions among interested parties. Close interrelationships between system hydraulics and biota transfer may be highlighted by noting that water velocities through piping directly influence shearing of biofilms from pipe surfaces, with potential for dislodging and releasing microbes entrained in the biofilm a not uncommon mechanism that may serve as an initiating event leading to biota transfer. Similarly, pressure transients may dislodge tubercles and shear biofilms that have accumulated in, e.g., low flow areas within the system (LeChevallier, 1990), resulting in release of elevated levels of the contaminants to the water column.

LeChevallier et al (2006, available at http://www.epa.gov/safewater/tcr/pdf/intrusion.pdf last accessed May 27, 2006) focused on risks linked to intrusion of contaminants into the distribution systems from pressure transients, which may identify similar risks in water transmission systems such as those outlined in DEIS (Reclamation 2005). While much of the current literature emphasizes the intrusion of chemical contaminants into water systems, the increasing awareness of risks associated with biological interlopers remains highly fraught with uncertainty, especially as that reflects outcomes related to hydraulic behaviors of the system, e.g., pressure transients. As summarized in Section 3, any change in fluid flow in a pipe (e.g., due to valve closure, pipe fracture, or pump stoppage) will result in an exchange of energy between flow and pressure; that is, a pressure transient. The magnitude of the pressure change will be influenced by the materials of construction, pipe characteristics, and the water velocity; hence, uncertainties associated with these system attributes must be considered in subsequent iterations of the design process. Operational characteristics can further affect the significance of pressure transients, including: non-networked and dead-end pipelines, a lack of elevated distribution system storage tanks, undulating topography, entrained air, valve characteristics, and frequent power failures of pumping stations (AWWSC 2002).

The significance of intrusion from a pressure transient—regardless of whether one's focus lies only in public health or in larger picture issues involving, e.g., fish and wildlife health—depends on the number and effective size of leaks, the type and amount of contaminant external to the distribution system, the frequency, duration, and magnitude of the pressure transient event, and the population exposed. Any contaminant exterior to the pipeline environment may enter the water transmission system, e.g., during a negative pressure event, with risk of intrusion increasing with system age. Biological contaminants are a concern because even with dilution, some microbes (e.g., viruses) could cause an infection with a single organism (see, e.g., Karim et al. 2001)

The frequency and magnitude of pressure transients reflect uncertainties that must be acknowledged in reiterative failure analyses companion to full engineering designs. Problems with low or negative pressure transients in water distribution networks have been reported in the literature (see, e.g., Walski and Lutes 1994, Qaqish et al. 1995), and could provide potential for entry of contaminants into water transmission and distribution pipelines. Surge control, particularly control of high-pressure events, has typically been considered for preventing pipe bursts and efforts have been directed at reducing the maximum pressures, yet negative pressure transients and their risk implications have only recently received attention. Mitigation or risk reduction measures potentially include, e.g., slow valve closure times, avoiding check valve slam, minimized resonance, air vessels, surge tanks, surge anticipation valves, air release valves, combination two-way air valves, vacuum break valves, check valves, surge suppressors, and by-pass lines with check valves (see, e.g., Cesario 1995, Skousen 2004). Efforts to reduce pipeline leakage are beneficial for water conservation, but also minimize risk potentials for microbial intrusion.

Uncertainties related to water transmission system aging. While this preliminary analysis simplified failures as being associated with water withdrawal, treatment, and transmission, a conceptual model of a process intended to address these and other infrastructural-related uncertainties is presented in Figure 7-16, and could be included in future investigations focused on detailed engineering designs (see also USGS [2005b]). As noted in Section 3 and in USGS (2005b), buried water transmission pipelines are subject to corrosion, soil movements, temperature fluctuations, rainfall, and system stresses in the continuous process of structural deterioration. These threats to a water transmission were summarized in Table 7-4 adapted from EPRI (2001), as cited at http://www.structint.com/tekbrefs/datasheets/buriedpiping/.

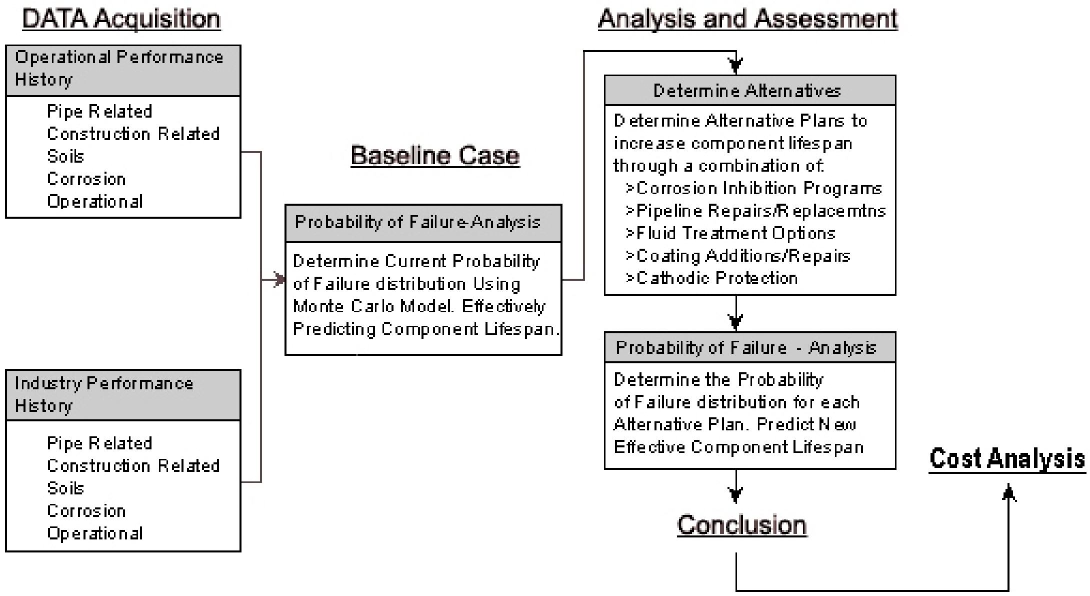

Figure 7-16. Process of life-cycle management for buried pipe (after EPRI 2001, modified after original figure posted at http://www.structint.com/tekbrefs/datasheets/buriedpiping/).

Various environmental mechanisms adversely affect long-term performance of buried pipelines, e.g., infrastructure degradation linked to various internal and external corrosion may be significant, leading to maintenance and repair issues as the transmission system ages (see Section 3). Depending on pipe specifications and materials and as piping ages, pipe and pipe coatings deteriorate (e.g., corrosion for iron pipe and other mechanisms for concrete or high-density polyethylene materials) which eventually leads to leaks or pipe breaks. Critical piping systems such as those proposed for addressing water needs of the Red River Valley—regardless of their focus on No Action or Action Alternatives—contain miles of buried piping whose failure can adversely impact transmission or distribution lines in the future. As standard practice suggests (see, e.g., Moser 2001 and references cited therein), in the northern Great Plains buried pipe will generally be placed no less than 7-7½ feet below ground surface (BGS) to prevent freezing, and the effects of frost-heave will be reduced if burial follows guidance available for construction on various soil types (see, e.g., see http://www.soils.usda.gov/technical/handbook/contents/

part618p2.html#29, Andersland Ladanyi 2004, USDA–NRCS 2003), depending on required elevations for pipeline segments throughout the transmission system.

Pipe standards for materials and installation are specified by American Water Works Association (AWWA; see, e.g., http://www.awwa.org/bookstore/Category.cfm?cat=3), American Society for Testing and Materials (ASTM; see, e.g., http://www.astm.org/cgi-bin/ SoftCart.exe/COMMIT/COMMITTEE/C13.htm?L+mystore+jvks6413+1125547345, last accessed August 31, 2005), and American Society of Civil Engineers (ASCE; see, e.g., http://www.asce.org/ instfound/codesandstandards.cfm, last accessed August 31, 2005). For example, transmission and distribution lines may be constructed of a variety of materials, but must withstand, e.g., internal and external pressures, including pressure transients, and be resistant to corrosion (see AWWA standards and manuals, and NACE citations in Section 8; see also "Corrosion considerations for buried metallic water pipe" July, 2004, Bureau of Reclamation, Technical Memorandum No. 8140-CC-2004-1). For example, as noted in Section 3, failure rates in DIP (as well as cast iron water pipes) are related to various soil properties, which may be mapped using geographical information systems (GIS) as illustrated in Section 4 for soil properties linked to corrosivity potentially associated with soils in Griggs County, North Dakota.[3] An interrelated group of uncertainties associated with the corrosivity of soils along pipeline routes once specified may be relatively easy to address by tapping into data sources readily available to project planners. Additionally, there are categorical tools available, e.g., the Ductile Iron Pipe Research Association (DIPRA) scoring system in part based on soil properties such as resistivity, pH, sulfides and moisture content, that would yield forecasts of soil-pipeline interactions potentially affecting system performance through time. Average pipe-failure rates are correlated with DIPRA scores for different soil environments present within pipe networks. Locally, empirical data may also be collected to validate forecasts derived from GIS-based which yield soil corrosivity and reactivity projections that can subsequently be linked to soil shrink–swell indices, enhancing the characterization of environmental conditions.

One commonly applied method to offset soil corrosivity and envisioned for incorporation into full engineering designs is cathodic protection, especially as a component critical to a long-term preventative maintenance program for ferrous pipe. Due to the continual corrosion process and age-related increases in pipe failures associated with ferrous pipes, cathodic protection is a

[3]Griggs County was used only as an example to illustrate resolution of county-wide data, e.g., on soil properties and how such data will be valuable to identifying pipe route captured by full design.

frequent tool applied to reducing risks associated with environmentally linked corrosion. Stainless steel bolts are also generally required in appurtenances to reduce the possibility of failure from corrosion. When hydraulic demands allow, PVC pipes may be used in the water transmission system. While PVC will not corrode, appurtenances connected to the line may also require cathodic protection if those components are prone to corrosion. Sacrificial anodes are generally used for isolated locations such as valves and metal vaults in PVC pipelines. Cathodic protection has been a method of choice water transmission and distribution systems (see, e.g., Peabody 1970, Heidersbach 1998, Shipilova and LeMay 2005), and may effectively defer risks directly linked to system aging through the installation of sacrificial anodes made of magnesium or zinc (depending on soil characteristics) underground at pipe depth. The anodes are connected to the pipe with insulated copper wires, with several anodes placed along the length of the pipeline. Spacing of the anodes dependent on the condition of the pipe, pipe size, soil resistivity and strength of stray electric ground currents. The sacrificial anode method utilizes galvanic anodes of zinc or magnesium that are packed in a low resistivity backfill selected to ensure that anode polarization will be inhibited. Cathodic protection in effect reverses the electrochemical process of corrosion by introducing a metal that is higher on the galvanic scale (the anode) and hence more likely to corrode. The protecting (sacrificial) anode becomes the metal that is depleted by corrosion rather than the pipe. The basic criterion for adequate cathodic protection is generally taken as the application of a protection current from the anodes equivalent to 10 mA per square meter of water main pipe surface (Kleiner and Rajani 2004b, Peabody 1970, 2001). Cathodic protection can help reduce age-related leakage from DIP, but pipes may also be coated and electrically isolated from stray current effects as additional countermeasures to control corrosion. Benefits of cathodic protection in water transmission pipelines will likely address, in part, uncertainties associated with age-dependent attributes of piping systems, including engineering costs which were not considered in this preliminary failure analysis. Regional analyses, however, indicate that cathodic protection would be a risk-reduction measure that should be incorporated into full system design. For example, studies on a water distribution system in an Ontario municipality retrofit suggest that pipe breaks are reduced in retrofitted systems, if cathodic protection is incorporated into pipe networks (Figure 7-17). Within the context of uncertainties related to a typical bath tub curve life-time distribution, cathodic protection could effectively delay onset of wear-out phase.

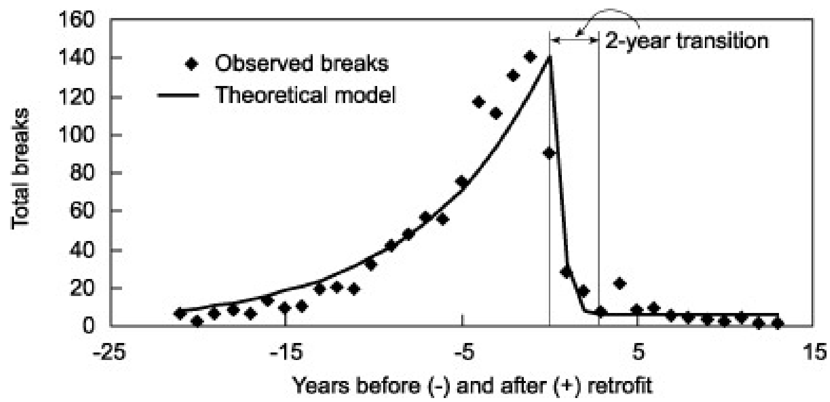

Figure 7-17. Breakage-rate pattern for pipes in an Ontario municipality (see Kleiner et al. 1998a,b for detail).

Uncertainties associated with existing data on pipe and other system component failures. Encountered data incorporated into this preliminary failure analysis present attributes that unavoidably capture uncertainty reflected in the interpretation of risks. As noted in USGS (2005a), encountered data are commonly collected in ecological and environmental studies, and are largely observational in character. In desktop analyses frequently completed in preliminary analyses, data are generally secondary (e.g., compiled by third parties such as government or industry sources) and are heterogeneous in nature. Yet, for preliminary desktop analysis, encountered data with their attendant uncertainties may better serve to identify project-critical data gaps, e.g., related to short-term and long-term system reliability.

For example, Xu, et al. (2003) identified algorithms for estimating the capacity reliability of ageing water distribution systems recognizing uncertainties in nodal demands and the pipe capacity. Uncertainties in the nodal demands and values of pipe roughness were evaluated using a probabilistic approach that provided accurate estimates of capacity reliability of a deteriorated pipe network, if dispersion in input random variables is small. Similarly, uncertainties in water transmission and distribution pipelines was considered by Boxall et al. (2004) in their efforts to forecast burst behavior of pipes in water distribution systems. These workers observed a number of uncertainties potentially linked to interpretation of statistical results achieved in the analysis process, including those related to data quality and quantity, lack of association between individual events and pipes, and the statistical techniques available and applied. Each of these uncertainties are also reflected in the preliminary failure analysis. Yet, despite these uncertainties the existing literature, as well as outcomes of the preliminary analysis completed here, indicated strong associations between burst rate, diameter and length, and a complex association with age of pipe. Various sources suggest that factors influencing pipe failures reflect the wide range of physical, chemical and loading factors that exists in a water pipeline's operating environment. These factors interact, which also influences potentials for failure. Categorically, these factors linked to uncertainty are related to loading, pipe diameter and material, corrosion, age or time-in-service, pipeline length, and third party actions.

Loading requirements of a water transmission system vary, and serve as a design criteria for any system. Under operating conditions a pipe is provided with uniform support over its entire length, yet uncertainties in this preliminary failure analysis (or more comprehensive analysis completed in parallel to an extensive hydraulic evaluation) may be associated with, e.g., poor initial installation or disturbance over time related to ground movements. The ability of pipes to resist such forces is a function of the material strength and the second moment of the cross-section (closely captured by cross-sectional area as noted previously; see Figure 7-7), perhaps most easily conveyed by looking at pressure-handling requirements of pipe. Pipes are designed to resist internal pressures of water flowing through them, with pressure being an important factor controlling pipe leaks. Beyond routine operating pressures, pipes are also exposed to greater forces under transient conditions, induced by sudden changes in operational conditions, such as pump switching, power failure and valve movements. The ability of a pipe to resist the stresses induced by internal pressure is a function of the tensile strength of the material and wall thickness (see, e.g., Moser 2001). Clearly, pipe loadings reflect uncertainties related to pipe diameter and material among other factors.

Smaller diameter pipes tend toward higher failure rates (see, e.g., Ciottoni 1983, Andreou and Marks 1986, and Walski et al. 1986). For example, early statistical analysis reported by Kettler and Goulter (1985) indicated a strong correlation between average breakage rate and diameter in asbestos cement and cast iron pipe, frequently displaying nearly linear decreases in failure rates with increasing main size, especially across materials considered in their study (cast-iron versus asbestos cement). Similarly, Shamir and Howard (1979) and Walski and Pelliccia (1982) recognized inverse relationships between breakage rate and diameter. Pipe material also serves as a source of uncertainty in this preliminary failure analysis, although the short-listed materials—DIP, ST pipe, and PVC pipe—demonstrate breakage rates that suggest a variety of pipe materials may serve engineering specification beyond those conceptual designs in the DEIS (Reclamation 2005). Differences in material strengths define a pipe's capacity to resist the loads and also dictates corrosion characteristics of interest to long-term planning. Not surprisingly, various workers (see, e.g., O'Day 1989, Grau 1991, Ahammed and Melchers, 1994, Duranceau et al. 2004) have identified corrosion as a major factor in the structural deterioration of water pipelines, especially for ferrous materials such as DIP and various cast-iron pipes. External corrosion of iron mains occurs primarily due to electrochemical reactions, which for water transmission and distribution lines may be focused on uniform, localized, galvanic, and concentration cell corrosion (see, e.g., AwwaRF/DVGW-TZW 1996). For example, O'Day (1989) suggested that galvanic corrosion was a primary factor influencing external deterioration of pipe, largely dictated by local soil properties such as resistivity, pH, redox potential and moisture content which yield reduced pipe-wall thickness as a result of corrosion (see, e.g., Ahammed and Melchers 1994). External corrosion is generally considered more significant to pipe aging than internal corrosion, although the latter sources of corrosion are more directly associated with declines in water quality (see, e.g., Holden et al. 1995, LeChevallier et al. 1993). Given the brief overview of the corrosion process in Section 3, it is not surprising these processes are directly related to pipe age or time-in-service, as a measure of exposure.

While age or time-in-service may not stand alone as the only indicator of pipe condition, time's role in fatigure, corrosion, and other mechanical processes provides a common basis for considering the relative contribution of risk factors potentially influencing water control system performance. Biological processes related to system function, e.g., the nominal function of membrane technologies or UV disinfection units, or to development of, e.g., biofilms in a water transmission system are similarly time-dependent. For example, Herbert (1994) noted that system age must be considered in combination with network condition and its vulnerabilities to more accurately evaluate water system assets. Indeed, as a source of uncertainty for the preliminary failure analysis reported herein, any conceptual designs must be viewed with caution and overly pessimistic or optimistic interpretations of risk outcomes projected, e.g., from life time distribution analysis forecast in Section 3, should be cautiously developed. From operational experience, Dyachkov (1994) observed that pipelines follow a range of life time distributions, each characterized by their own periods of "useful service life." O'Day (1982) had earlier suggested that age alone was a poor indicator of burst rate in a study focused on cast iron pipe. Nonetheless, age must be as a primary factor influencing pipe failure, particularly given the existing literature supporting its value as an indicator of system performance (see, e.g., Goulter and Kazemi 1988, 1989, Fleming and Lydell 2004, Xu et al. 2003).

Pipe leaks generally anticipate bursts, and water loss as a measure of "background leakage" is associated with system age—as trends in a system's water leakage increase with age, the possibility of pipe bursts increase. While association between age and pipe failure varies as a function of other environmental factors, e.g., soil properties, age indicates operational life of the pipe within a water transmission system, which is directly linked to exposure to the surrounding environment, and the time it has been subject to both internal and external loads. Age may also be a surrogate indicator of the design and construction practice and the quality and strength of the material itself.

As noted in USGS (2005b), pipe burst rate varies as a linear function of pipe length—the longer the pipe, the more there is to be exposed to conditions promoting bursting. This may go beyond the simple arithmetic function of, "the more pipe, the more breaks," may also reflect contributing risk factors such as the heterogeneity of soil properties across a wide range of environmental settings or differences in support from surrounding fill or differences in ground movement across various reaches of pipeline. Length may also be a surrogate for connection density (contrast, e.g., GDU Water Supply Replacement pipeline with all other Action Alternatives), which may reflect failure risks captured by factors associated with pipeline length that go beyond the simple measure of distance (e.g., number of transitions between different pipe diameters, differences in stresses associated with pipeline configuration). Ground conditions also influence stresses potentially contributing to pipe failure, e.g., due to ground movement or other geotechnical processes such as soil shrinkage and swell, and frost heave, and other seasonal events (see, e.g., Lackington 1991, Palmer and Williams 2003 with related discussions, Coduto 1999). Interactions related to soil properties and ground movement are highly likely to occur, given a soil's physicochemical properties are highly correlated, e.g., highly aggressive and shrinkable soil generally have attributes linked to high corrosivity. While the preliminary failure analysis presented in this work merely illustrated the potential application of mapping soil properties as a tool, e.g., to aid pipeline routing to reduce risks, others (see, e.g., Grau 1991, Jarvis and Hedges 1994) have developed soil corrosivity maps as tools for highlighting areas of high burst risk.

As indicated early in this document, third party interactions associated with system failures was not considered for these initial evaluations of conceptual designs in the DEIS (Reclamation 2005). Yet, quality of installation and workmanship may well be critical to evaluations of pipe failure, and should be incorporated into failure analyses completed in conjunction with fully specified engineering designs. For example, EPRI (2002) observed that material flaws, "out-of-specification" manufacture, or improper installation may introduce weaknesses to pipe that are realized only through loss of service life years following construction. Less than standard construction practice may lead to failure due to improper bedding, which in effect is a source of uncertainty not captured in this preliminary failure analysis.

Global uncertainties reflected in preliminary failure analysis. Much of the preliminary analysis hinged on existing failure data for pipe and components necessary to conceptual designs such as pumps, valves, and treatment processes. Given the relatively coarse-grain analysis supported by conceptual designs identified in the DEIS (Reclamation 2005), uncertainties directly related to the preliminary nature of the design are apparent. For example, given the list of factors briefly identified, composite failure rates were the only values supporting the analysis of risks associated with system failure. As noted in USGS (2005a), the composite values for failure rates for a variety of system components clearly underscore the analytical limitations of encountered data. Compilations of pipe break and burst data illustrate the uncertainties inherent to existing data, e.g., as those may reflect differences in derivation.

Historically, Clark et al. (1982) found that following an initial pipe failure, subsequent failures increased exponentially as a function of time. Likewise, in a study restricted to pipes greater than 8 inches (200mm) in diameter Andreou and Marks (1986) found that the time to next break decreased as each break occurred. Goulter and Kazemi (1988) found that failures were spatially-linked more often than not, e.g., failures tended to occur within a short distance of neighboring failures. Various explanations have been suggested to account for such occurrences, including soil movement caused by the changing moisture content from the leaking water or exposure of the soil to the extreme cold of the air and disturbance of the bedding during repair (see, e.g., Skipworth et al 2002). Regardless of the causal factors leading to such observations, these and other studies urge caution in the interpretation of any preliminary analysis. Mechanisms of pipe failure more often than not occur as combinations of loading and structural deterioration, and reflect a range of factors related to material, diameter, length and age.

Addressing uncertainties in system design. Interpretation of risks characterized in this preliminary failure analysis focus on future iteration of the risk analysis-system design process. Design of a water withdrawal, treatment, and transmission system requires such preliminary analyses in order to focus on questions that help identify levels of risk tolerance, the characterization of acceptable risks, and moving the process beyond conceptual designs. For example, pipeline designs developed as outcomes of the DEIS must fully address sizing, line pipe configuration and routing, as well as developing the transmission system sufficient to maintain the risk reduction anticipated during water withdrawal and treatment.

Within the context of uncertainties constraining interpretation of this preliminary failure analysis, most of these uncertainities will be addressed in full engineering designs developed following revision of the DEIS (Reclamation 2005). Detailed pipeline design provides a range of benefits, particularly with respect to its optimization. All pipelines are unique, primarily because of the number and range of variables that must be specified. For example, conceptual designs present basic background that leads to full design specification of, e.g., pipe-wall thickness and pipe diameter, burial depth, overall length, and ground conditions including environmental restraints, which provide a starting point for addressing uncertainties currently reflected in the preliminary failure analysis. Safety-related design elements and risk countermeasures incorporated into a full design should protect the water withdrawal and treatment modules and pipeline assets to assure as a risk of failure as low as reasonably practicable (ALARP) given the current technology, thus keeping the system in service longer without mishap. Any design cannot make a pipeline absolutely safe. As the water withdrawal, treatment, and transmission system gains greater resolution, quantitative risk analysis and structural reliability assessments should extend this preliminary failure analysis, with a particular focus on uncertainties presently associated with conceptual designs and coarse-grained data.

For example, conceptual designs in the DEIS (Reclamation 2005) set the stage for full-designed systems wherein, e.g., design pressures, flow rates, pipe diameters and pipeline length, and routing are detailed. Environmental data, e.g., linked to routing may be more fully characterized, especially with respect to soils (physicochemical characteristics) and how aggressive these soils will be relative to corrosion potential. From the conceptual designs already in hand, measures of rainfall, elevation changes, temperature variations, and ground movements (e.g., frost heave potential and earthquake hazards) are well characterized. Complete specification of route data would address uncertainties related to, e.g., number and types of crossings, special areas having high environmental sensitivity, and geophysical information that might suggest special construction techniques beyond those general descriptions in the conceptual designs.

Final selection of pipe materials will help focus subsequent failure analysis, as suggested by the discussion of pipe-break rates in Section 3. Also, the potential incorporation of two types of pipe material, e.g., DIP and PVC pipe or ST pipe and PVC pipe, may be associated with uncertainty that should be easily resolved upon full design specification. Similarly, incorporation of cathodic protection into system design may be more fully incorporated into a detailed failure analysis, reducing uncertainties that influence age-related discussions of system failure potentially linked to biota transfer. Although briefly considered in the conceptual designs, pipe jointing may be more fully considered in reiterative failure analysis completed as Action Alternatives are advanced to full design specification (e.g., rubber gasketed bell and spigot joints, or restrained joints as indicated). The use of reliability-based design for new pipelines may yield final designs considered “acceptably safe” with respect to biota transfers and extend a design practice beyond accepted stress-based design codes (see, e.g., Hopkins 1998, Mielke 2004, Muhlbauer 2004, Reed et al. 2004, Kleiner et al. 2005, Mohitpour et al. 2005).

Overall, system integrity, particularly as those are captured by loss of pipeline reliability, must be viewed within the context of uncertainty. For example, loss of containment commonly linked to leaks, breaks, and bursts have historically been associated with human factors (e.g., faults in construction and operation or other third-party actions), design flaws, materials failures, extreme conditions or environments, and most commonly and importantly, combinations of these factors. Although strictly human factors, e.g., related to third-party actions and breaches in system security were not considered in this preliminary failure analysis, these factors were identified in Table 7-4. Materials failures commonly linked to pipeline failures include mechanical damage (e.g., linked to installation), fatigue cracks and other material defects, weld cracks (as might be encountered in joint-welded pipes), and external or internal corrosion. Metal fatigue in pipelines and other mechanical components of the water withdrawal, treatment, and transmission system are commonly linked to repeated cycling of the system load and the progressive local damage linked to fluctuating stresses and strains on the material, e.g., metal fatigue cracks will be initiated and propagated in regions where the strain is most severe. Uncertainties associated with fatigue failure may be considered early in system design through, e.g., eliminating or reducing stresses by changing pipeline configuration, streamlining pipe layout, or incorporate countermeasures to address unavoidable conditions.

As the preceding discussion indicates, pipeline design beyond those conceptual configurations in the DEIS (Reclamation 2005) will be critical to the risk reduction process, particularly as those related to uncertainties reflected in the preliminary failure analysis summarized in Section 3. When considered in light of the ecological characterization of the project area summarized in Section 4, no better illustration of the interrelationships between pipeline and “habitat at risk” that might influence routing can be seen than that focused on stream crossings and pipeline installation relative to environmentally sensitive areas.

To address uncertainty and reduce risk potentially associated with biota transfers and to protect, e.g., fish and wildlife and their habitats, maintaining the functionality of aquatic, terrestrial, and riparian ecosystems should be included as a design criteria for the transmission system. For example, pipeline installation should consider stream and wetland crossings within the context of Best Management Practices (BMP's) that reflect habitat assessments completed in conjunction with pipeline surveys necessary to the routing process (see, e.g., Harper and Trettel 2002, Zwirn 2002, Oil and Gas Commission 2004a,b). Pipeline crossings involve many processes that may impact the surrounding environment, including construction activities, habitat disturbance, removal of riparian and wetland vegetation, and the stream crossing itself. Direct impacts will likely be short-term, construction-related (see, e.g., Harper and Trettel 2002, Zwirn 2002), and indirect or long-term impacts will depend on the type of crossing, construction techniques used for installation (e.g., trenching or horizontal directional drilling, if appropriate), and maintenance.

Similarly, rights-of-way (ROWs) may influence pipeline design and may be leveraged to reduce risk and attendant uncertainties as those relate to biota transfer. For example, managing revegetation subsequent to construction disturbance associated with pipeline installation may be critical to reducing uncertainties related to invasion by invasive species, perhaps not directly transferred to areas of concern via interbasin water diversions, but enabled to establish beach heads in disturbed habitats associated with pipeline installation. Construction practices yielding short-term disturbance habitats may unintentionally contribute indirectly to successful invasions, e.g., of plants considered in USGS (2005a). Effective management of construction-related effects potentially of concern to issues of biota transfer becomes a matter of bringing together the needs of transmission pipelines with those of biota dependent on habitats at risk. The use of habitat management and restoration techniques in ROWs management may serve long-term planning related to system performance (e.g., security from third party actions), while reducing uncertainties captured by biota transfers and species invasions.

Understanding and communicating uncertainties and limitations associated with full engineering designs should be incorporated into risk management plans for any Action Alternative regardless of whether it involves an interbasin water transfer or not. Developing these plans within the context of a system's life cycle directly addresses uncertainties reflected in the life time distribution of the system, which ultimately yields a more reliable system in its long-term operation and management. Life cycle analysis is a dynamic process that can help inform decision-makers, while reducing risks through design, construction, and operation of a system such as those envisioned to meet the water demands of the Red River Valley (see, e.g., http://www.epa.gov/ORD/NRMRL/lcaccess/lca101.htm last accessed May 14, 2006).

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[1]A compilation of reference materials included as embedded citations in the main body of this report, and materials supporting the analysis and interpretation of findings derived from the analysis completed as part of this failure and consequence analysis.

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Appendix 1. Failure analysis primer

While a comprehensive review of the tools used in analysis is not necessary to the management of risks, in this appendix we briefly discuss types of data, data distributions (especially as those relate to biota transfers and failures in control systems), reliability analysis, and the evaluation of complex systems such as those envisioned as engineering controls (e.g., water treatment and distribution system) considered within the context of risk reduction in the current investigation. For a more extensive treatment of any of the analytical tools the reader is referred to the references in Section 8 or to those included as part of this appendix.

A1.0 Types of Data: Categorical data and measurement data

Categorical data reflect objects being grouped into categories based on some qualitative trait, and the resulting data are merely labels (Figure A1-1). Common day examples of categorical data are hair color, flower colors, sex, and species occurrence data (present/absent data or more precisely, found/not found data). A simple review of even these common day examples indicates that categorical data can also be classified based upon the number of categories that are potentially characteristic of all members of the population.

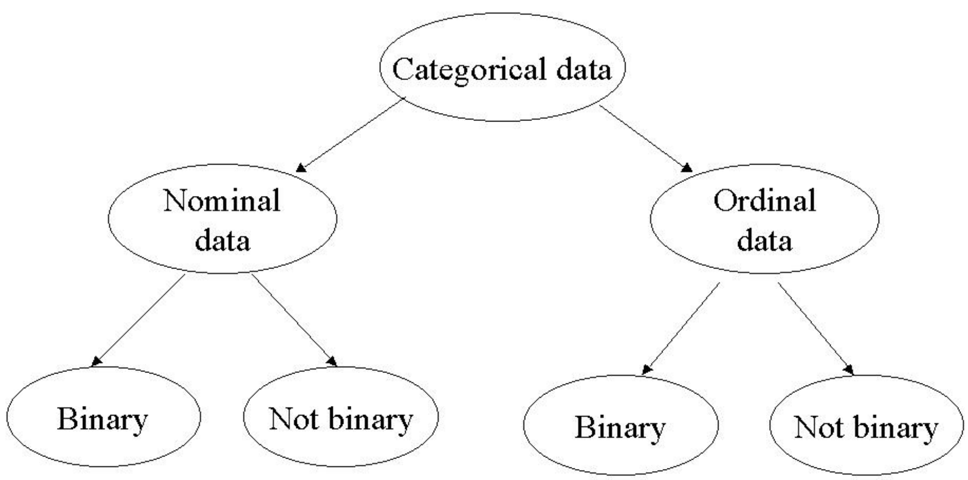

Figure A1-1. Types of categorical data.

Categorical data are classified as being nominal, ordinal, or binary (dichotomous) in character. Nominal data are a type of categorical data in which objects fall into unordered categories (e.g., flower colors). In contrast, ordinal data are categorical data in which order is important, e.g., developmental stages of some invertebrates are an ordered set referred to as eggs, larvae, juveniles, and adults or pathological states such as morbidity may be scored as none, mild, moderate, and severe. Binary or dichotomous data are categorical data that occur as one of two possible states; that is, there are only two independent categories, e.g., species occurrence (e.g., present/absent). Binary data can either be nominal or ordinal.

Measurement data are those that are measured, based on some quantitative trait and the resulting data are set of numbers, e.g., height, weight, age, number of organisms in a region, or stream velocity (Figure A1-2). Measurement data are classified as discrete or continuous, where discrete measurement data occur as only certain values; that is, there are gaps between the values. Values for discrete data are generally whole numbers and occur at count data, e.g, population counts such as number of fish in a pond. In contrast to discrete measurement data, continuous measurement data may occur as any whole number plus take on any value in the interval between whole numbers, e.g., distance, height, and age. Categorical data are commonly summarized using "percentages" (or "proportions"), and measurement data are typically summarized using "averages" (or "means") or some descriptive statistic that characterizes a particular attribute of a sample of numbers taken from a population of interest.

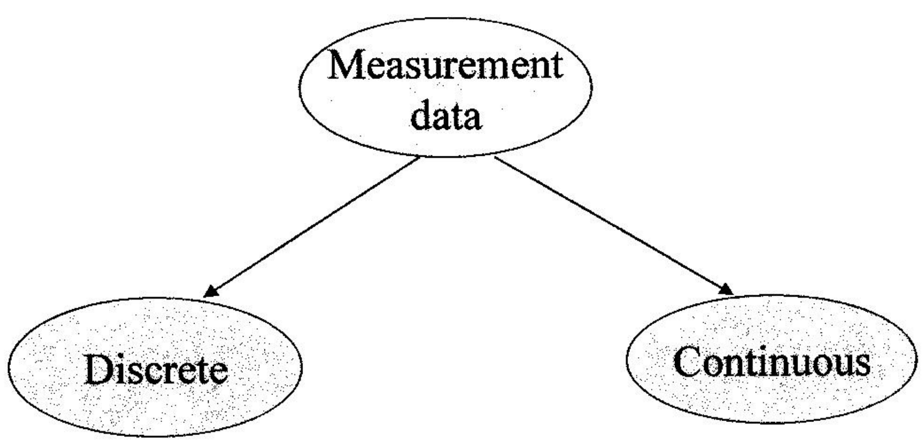

Figure A1-2. Types of measurement data.

A1.2 Data distributions

In data mining operations such as those implemented for the current investigation, an understanding of data and their characteristic distributions are necessary to conduct an analysis of risks, especially for probabilistic analyses (see, e.g, Bedford and Cooke 2001). Predicted or forecasted outcomes of risk scenarios, be those characterized by qualitative or quantitative methods, that capture the concerns of stakeholders reflect issues incorporated into conceptual models of alternative events (such as biota transfers yielding species invasions or shifts in metapopluations). Inevitably, data mining and the evaluation of encountered data has been completed in the absence of a fully characterized distribution of data, which is common in studies such as ours, in part, owing to dependence on diffuse data sources collected across multiple publications across a wide range of time. Our current work, however, frequently requires assumptions of data distributions likely characteristic of these data compiled during the course of the study; hence, a brief overview of frequently encountered data distributions and their interrelationships is included in this appendix in order to better characterize risks, and in particular uncertainties associated with these risks (see standard references and online sources such as Weisstein (1999), e.g., http://mathworld.wolfram.com/about/mathworld.html for source materials for this portion of Appendix 1 and additional detail on data distributions).

Bernoulli Distribution. The Bernoulli distribution is a discrete distribution having two possible outcomes labelled by $n = 0$ and $n = 1$ in which $n = 1$ ("success") occurs with probability p and $n = 0$ ("failure") occurs with probability $q \equiv 1 - p$, where $0 < p < 1$ (Figure A1-3; see, e.g., Evans, et al 2000; Balakrishnan and Nevzorov, 2003). As such, the distribution has probability function:

$$P(n) = \begin{cases} 1-p & \text{for } n = 0 \\ p & \text{for } n = 1, \end{cases}$$

which can also be written

$$P(n) = p^n (1-p)^{1-n}.$$

The corresponding distribution function is

$$D(n) = \begin{cases} 1-p & \text{for } n = 0 \\ 1 & \text{for } n = 1. \end{cases}$$

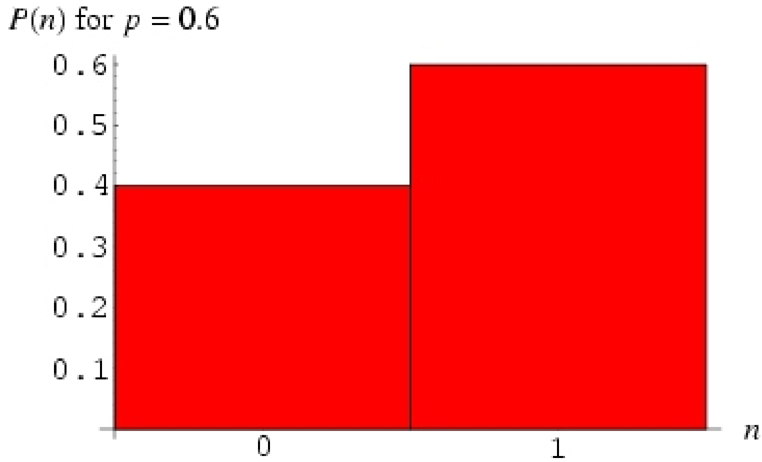

Figure A1-3. Bernoulli distribution.

The performance of a fixed number of trials with fixed probability of success on each trial is known as a Bernoulli trial, which is an experiment in which *s* trials are made of an event with probability *p* of success in any given trial.

The distribution of heads and tails in coin tossing is an example of a Bernoulli distribution with $p = q = 1/2$. The Bernoulli distribution is the simplest discrete distribution and is the building block for other more complicated discrete distributions. The distributions of a number of variate types are based on sequences of independent Bernoulli trials that are constrained in some way, e.g., the binomial distribution is characterized by the number of successes in *n* trials (Evans et al 2000; Balakrishnan and Nevzorov 2003).

The characteristic Bernoulli function is

$$\phi(t) = 1 + p(e^{it} - 1),$$

and mean , variance , skewness , and kurtosis are then

$$\mu = p$$

$$\sigma^2 = p(1-p)$$

$$\gamma_1 = \frac{1-2p}{\sqrt{p(1-p)}}$$

$$\gamma_2 = \frac{6p^2 - 6p + 1}{p(1-p)}.$$

To find an estimator $\hat{p}$ for the mean of a Bernoulli population with population mean *p*, let *N* be the sample size and suppose *n* successes are obtained from the *N* trials. Assume an estimator given by

$$\hat{p} \equiv \frac{n}{N},$$

so that the probability of obtaining the observed *n* successes in *N* trials is then

$$\binom{N}{n} p^n (1-p)^{N-n}.$$

The expectation value of the estimator $\hat{p}$ is therefore given by

$$\begin{aligned} \langle \hat{p} \rangle &= \sum_{n=0}^{N} p \binom{N}{n} p^n (1-p)^{N-n} \\ &= (1-p)^N \left(\frac{1}{1-p} \right)^N p = p, \end{aligned}$$

so $\hat{p}$ is indeed an unbiased estimator for the population mean *p*.

Binomial Distribution. The binomial distribution gives the discrete probability distribution $P_p(n|N)$ of obtaining exactly *n* successes out of *N* Bernoulli trials, where the result of each Bernoulli trial is true with probability *p* and false with probability $q = 1 - p$ (see, e.g., Evans et al 2000; Balakrishnan and Nevzorov 2003). The binomial distribution is therefore given by:

$$\begin{aligned} P_p(n|N) &= \binom{N}{n} p^n q^{N-n} \\ &= \frac{N!}{n!(N-n)!} p^n (1-p)^{N-n}, \end{aligned}$$

where $\binom{N}{n}$ is a binomial coefficient. Figure A1-4 illustrates the distribution of n successes out of $N = 20$ trials with $p = q = 1/2$.

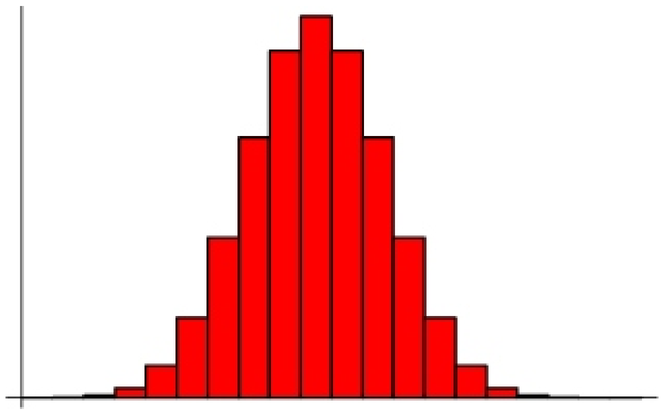

Figure A1-4. Binomial distribution.

The probability of obtaining *more* successes than the n observed in a binomial distribution is

$$P = \sum_{k=n+1}^{N} \binom{N}{k} p^k (1-p)^{N-k} = I_p(n+1, N-n),$$

where

$$I_x(a,b) \equiv \frac{B(x;a,b)}{B(a,b)},$$

$B(a,b)$ is the beta function , and $B(x;a,b)$ is the incomplete beta function.

The characteristic function for the binomial distribution is

$$\phi(t) = (q + pe^{it})^n$$

(see, e.g., Evans et al 2000; Balakrishnan and Nevzorov 2003), and the skewness and kurtosis are

$$\gamma_1 = \frac{1-2p}{\sqrt{Np(1-p)}}$$

$$= \frac{q-p}{\sqrt{Npq}}$$

$$\gamma_2 = \frac{6p^2 - 6p + 1}{Np(1-p)}$$

$$= \frac{1 - 6pq}{Npq}.$$

The mean deviation is given by

$$\mathrm{MD} = \sum_{k=0}^{N} |k - Np| \binom{N}{k} p^k (1-p)^{N-k}.$$

For the special case $p = q = 1/2$, this is equal to

$$\mathrm{MD} = 2^{-N} \sum_{k=0}^{N} \binom{N}{k} \left|k - \tfrac{1}{2}N\right|$$

$$= \begin{cases} \frac{N!!}{2(N-1)!!} & \text{for } N \text{ odd} \\ \frac{(N-1)!!}{2(N-2)!!} & \text{for } N \text{ even,} \end{cases}$$

where $N!!$ is a double factorial . For N = 1, 2, ..., the first few values are therefore 1/2, 1/2, 3/4, 3/4, 15/16, 15/16, ... A complete derivation is not included here. However, treating the distribution as continuous,

$$\lim_{N \to \infty} \sum_{n=0}^{N} P(n) \approx \int P(n)\, dn = \int_{-\infty}^{\infty} P(\tilde{n} + \eta)\, d\eta = 1.$$

Since each term is of order $1/N \sim 1/\sigma^2$ smaller than the previous, we can ignore terms higher than B_2, so

$$P(n) = P(\tilde{n}) e^{-|B_2|\eta^2/2}.$$

The probability must be normalized, so

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/(2\sigma^2)}$$

$$\int_{-\infty}^{\infty} P(\tilde{n}) e^{-|B_2|\eta^2/2}\, d\eta = P(\tilde{n})\sqrt{\frac{2\pi}{|B_2|}} = 1,$$

and

$$P(n) = \sqrt{\frac{|B_2|}{2\pi}} e^{-|B_2|(n-\tilde{n})^2/2}$$

$$= \frac{1}{\sqrt{2\pi Npq}} \exp\left[-\frac{(n-Np)^2}{2Npq}\right].$$

Defining $\sigma^2 \equiv Npq$,

$$P(n) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(n-\tilde{n})^2}{2\sigma^2}\right],$$

which is a normal distribution. For $p \ll 1$, a different approximation procedure shows that the binomial distribution approaches the Poisson distribution (see Haight 1967).

Normal distribution and the Central Limit Theorem. A normal distribution in a variate X with mean μ and variance σ^2 has probability function on the domain $x \in (-\infty, \infty)$. The term "normal distribution" or "Gaussian distribution" are commonly used in reference to this distribution, and because of its curved flaring shape, social scientists refer to it as the "bell curve" (Figure A1-5; see Patel and Read, 1982).

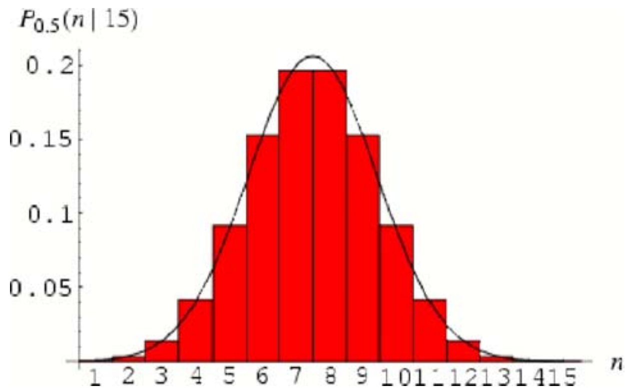

Figure A1-5. Normal distribution.

The so-called "standard normal distribution" is given by taking $\mu = 0$ and $\sigma^2 = 1$ in a general normal distribution. An arbitrary normal distribution can be converted to a standard normal distribution by changing variables to $Z \equiv (X - \mu)/\sigma$, so $dz = dx/\sigma$, yielding:

$$P(x)\,dx = \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\,dz.$$

The normal distribution function $\Phi(z)$ gives the probability that a standard normal variate assumes a value in the interval $[0, z]$,

$$\Phi(z) \equiv \frac{1}{\sqrt{2\pi}} \int_0^z e^{-x^2/2}\,dx = \tfrac{1}{2}\,\mathrm{erf}\left(\frac{z}{\sqrt{2}}\right),$$

where erf is a function sometimes called the error function; neither $\Phi(z)$ nor erf can be expressed in terms of finite additions, subtractions, multiplications, and root extractions. Consequently, both must be either computed numerically or otherwise approximated.

The normal distribution (Figure A1-5) is the limiting case of a discrete binomial distribution $P_p(n|N)$ as the sample size N becomes large, in which case $P_p(n|N)$ is normal with mean and variance

$$\mu = Np$$

$$\sigma^2 = Npq,$$

respectively, when $q \equiv 1 - p$.

The distribution $P(x)$ is properly normalized since

$$\int_{-\infty}^{\infty} P(x)\, dx = 1.$$

The cumulative distribution function, which gives the probability that a variate will assume a value $\leq x$, is then the integral of the normal distribution,

$$D(x) \equiv \int_{-\infty}^{x} P(x')\, dx'$$

$$= \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e^{-(x'-\mu)^2/(2\sigma^2)}\, dx'.$$

$$= \frac{1}{2}\left[1 + \operatorname{erf}\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right],$$

where erf is again called the error function.

Normal distributions have many convenient properties, so random variates with unknown distributions are often assumed to be normal. Although this can be a dangerous assumption, it is often a good approximation due to a surprising result known as the Central Limit Theorem . This theorem states that the mean of any set of variates with any distribution having a finite mean and variance tends to the normal distribution. Many common attributes conform to a normal distribution, with few members at the high and low ends and many in the middle. Because the normal distribution occurs frequently, there is a tendency to invoke assumptions of normality in situations where they may not be applicable (Whittaker and Robinson 1967).

The unbiased estimator for the variance of a normal distribution is given by

$$\sigma^2 = \frac{N}{N-1} s^2,$$

where

$$s \equiv \frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2,$$

so

$$\mathrm{var}(\bar{x}) = \frac{s^2}{N-1}.$$

The characteristic function for the normal distribution is

$$\phi(t) = e^{imt - \sigma^2 t^2/2},$$

and the variance , skewness , and kurtosis excess are given by

$$\mathrm{var}(x) = \sigma^2$$

$$\gamma_1 = 0$$

$$\gamma_2 = 0.$$

The variance of the sample variance s^2 for a general distribution is given by

$$\mathrm{var}(s^2) = \frac{(N-1)[(N-1)\mu_4 - (N-3)\mu_2^2]}{N^3},$$

which simplifies in the case of a normal distribution to

$$\mathrm{var}(s^2) = \frac{2\sigma^4(N-1)}{N^2}$$

(Kenney and Keeping 1951). If $P(x)$ is a normal distribution, then

$$D(x) = \frac{1}{2}\left[1 + \operatorname{erf}\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right],$$

so variates X_i with a normal distribution can be generated from variates Y_i having a uniform distribution in (0,1) via

$$X_i = \sigma\sqrt{2}\,\operatorname{erf}^{-1}(2Y_i - 1) + \mu.$$

The normal distribution is also a special case of the chi-squared distribution , since making the substitution

$$\tfrac{1}{2}z \equiv \frac{(x-\mu)^2}{2\sigma^2}$$

gives

$$d(\tfrac{1}{2}z) = \frac{(x-\mu)}{\sigma^2}\,dx = \frac{\sqrt{z}}{\sigma}\,dx.$$

Now, the real line $x \in (-\infty, \infty)$ is mapped onto the half-infinite interval $z \in [0, \infty)$ by this transformation, so an extra factor of 2 must be added to $d(z/2)$, transforming $P(x)\,dx$ into

$$P(z)\,dz = \frac{1}{\sigma\sqrt{2\pi}} e^{-z/2} \frac{\sigma}{\sqrt{z}}\, 2(\tfrac{1}{2}\,dz)$$

$$= \frac{e^{-z/2} z^{-1/2}}{2^{1/2}\Gamma(\frac{1}{2})}\,dz$$

(Kenney and Keeping 1951), where use has been made of the identity $\Gamma(1/2) = \sqrt{\pi}$.

Poisson distribution and rare events. A Poisson process is one that satisfies the following properties:

- The numbers of changes in nonoverlapping intervals are independent for all intervals.
- The probability of exactly one change in a sufficiently small interval $h \equiv 1/n$ is

$$P = \nu h \equiv \nu / n,$$

where ν is the probability of one change and n is the number of trials.

- The probability of two or more changes in a sufficiently small interval h is essentially 0.

In the limit of the number of trials becoming large, the resulting distribution is called a Poisson distribution (Figure A1-6; see Haight 1967).

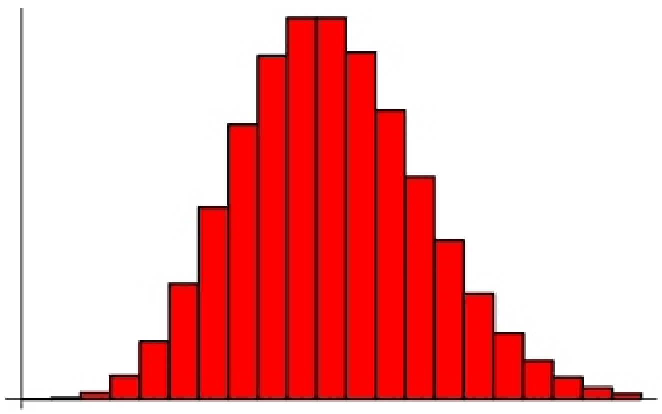

Figure A1-6. Poisson distribution.

Given a Poisson process, the probability of obtaining exactly n successes in N trials is given by the limit of a binomial distribution

$$P_p(n|N) = \frac{N!}{n!(N-n)!} p^n (1-p)^{N-n}.$$

Viewing the distribution as a function of the expected number of successes $\nu \equiv Np$ instead of the sample size N for fixed p, the equation then becomes

$$P_{\nu/N}(n|N) = \frac{N!}{n!(N-n)!} \left(\frac{\nu}{N}\right)^n \left(1 - \frac{\nu}{N}\right)^{N-n},$$

Letting the sample size N become large, the distribution then approaches:

$$P_\nu(n) = \lim_{N \to \infty} P_B(n)$$

$$= \lim_{N\to\infty} \frac{N(N-1)\cdots(N-n+1)}{n!} \frac{\nu^n}{N^n} \left(1-\frac{\nu}{N}\right)^N \left(1-\frac{\nu}{N}\right)^{-n}$$

$$= \lim_{N\to\infty} \frac{N(N-1)\cdots(N-n+1)}{N^n} \frac{\nu^n}{n!} \left(1-\frac{\nu}{N}\right)^N \left(1-\frac{\nu}{N}\right)^{-n}$$

$$= 1 \cdot \frac{\nu^n}{n!} \cdot e^{-\nu} \cdot 1$$

$$= \frac{\nu^n e^{-\nu}}{n!},$$

which is known as the Poisson distribution (see, e.g., Haight 1967; Papoulis 1984; Pfeiffer and Schum 1973). Note that the sample size *N* has completely dropped out of the probability function, which has the same functional form for all values of ν.

The Poisson distribution is normalized so that the sum of probabilities equals 1, since

$$\sum_{n=0}^{\infty} P_\nu(n) = e^{-\nu} \sum_{n=0}^{\infty} \frac{\nu^n}{n!} = e^{-\nu} e^{\nu} = 1.$$

The mean , variance , skewness , and kurtosis are

$$\mu = \nu$$

$$\sigma^2 = \nu$$

$$\gamma_1 \equiv \frac{\mu_3}{\sigma^3} = \frac{\nu}{\nu^{3/2}} = \nu^{-1/2}$$

$$\gamma_2 \equiv \frac{\mu_4}{\sigma^4} - 3 = \frac{\nu(1+3\nu)}{\nu^2} - 3$$

$$= \frac{\nu + 3\nu^2 - 3\nu^2}{\nu^2} = \nu^{-1}.$$

The characteristic function for the Poisson distribution is

$$\phi(t) = e^{\nu(e^{it}-1)}$$

(Haight 1967; Papoulis 1984), and the cumulative function is

$$K(h) = \nu(e^h - 1) = \nu(h + \tfrac{1}{2!}h^2 + \tfrac{1}{3!}h^3 + \ldots),$$

so

$$\kappa_r = \nu.$$

The Poisson distribution can also be expressed in terms of

$$\lambda \equiv \frac{\nu}{x},$$

the rate of changes, so that

$$P_\nu(n) = \frac{(\lambda x)^n e^{-\lambda x}}{n!}.$$

A1.3 Reliabililty analysis

As background to the current investigation and to encourage future iterations of this analysis consider the critical interactions between biological and ecological systems and the role that engineering systems play in reducing risks, a brief overview of failure analysis follows. For more comprehensive technical guidance on failure analysis and its potential value in evaluating risks and consequences, the reader is referred to Barlow (1998), Blischke and Parbhakar Murthy (2000), and NIST/SEMATECH (2004).

Repairable and non-repairable systems and lifetime distribution models. A repairable system is one which can be restored to satisfactory operation following some scheduled or unscheduled action to remedy a departure from acceptable performance (a failure), e.g., control systems involving water filtration will have a routine maintenance schedule to reduce risks of failure in treatment system, or ecosystems may recover following unsuccessful species invasions. When discussing the rate at which failures occur during system operation (and are then repaired), an engineer will define a "Rate Of Occurrence Of Failure" (ROCF) or "repair rate" which would be roughly equivalent to the restoration ecologist's term of "recovery rate." While the engineer actively develops corrective action plans (e.g., scheduled maintenance), restoration ecologists may assume active or passive roles in the recovery process (see, e.g., Jordan et al 1987; Manci 1989; FISRWG, 1998). For engineering systems, “failure rates” or “hazard rates” are terms applied to the first failure times for a population of non-repairable components or to non-repairable systems. Biological analogs of non-repairable components or non-repairable systems would be characterized as aging-related events (e.g., decreased fecundity) commonly measured as changes in survivorship (for example) in life-table analysis. A non-repairable population is one for which individual items that fail are removed permanently from the population. While the system may be repaired by replacing failed units from either a similar or a different population, the members of the original population dwindle over time until all have eventually failed. The comparison to cohorts and their passage through the population ecologist’s life table are clearly evident (see, e.g., Caswell 2001).

Tools for evaluating non-repairable populations. In general, population models used to describe unit lifetimes are known as lifetime distribution models regardless of whether the populations of interest are biological or engineering in origin. A population is generally considered to be all of the possible unit lifetimes for all of the units, and a random sample of size n from this population is the collection of failure times observed for a randomly selected group of n units. A lifetime distribution model can be any probability density function (or PDF), $f(t)$, defined over the range of time from $t = 0$ to $t =$ infinity. The corresponding cumulative distribution function (or CDF), F(t), characterizes the probability that a randomly selected unit will fail by time t. Figure A1-7 illustrates the relationship between $f(t)$ and $F(t)$. The lifetime CDF may be characterized by $F(t)$ as (1) $F(t)$ = the area under the PDF $f(t)$ to the left of t; (2) $F(t)$ = the probability that a single randomly chosen new unit will fail by time t; and (3) $F(t)$ = the proportion of the entire population that fails by time t.

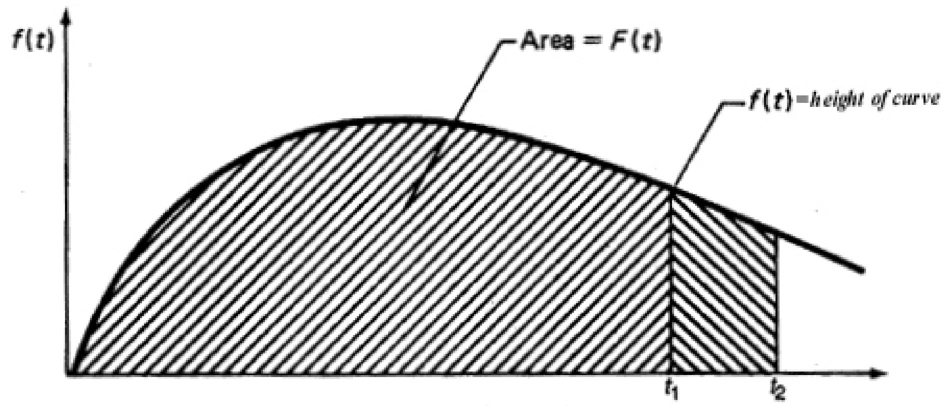

Figure A1-7. Cumulative distribution function for lifetime model.

The above figure also shows a shaded area under *f(t)* between the two times t_1 and t_2. This area is $[F(t_2) - F(t_1)]$ and represents the proportion of the population that fails between times t_1 and t_2 (or the probability that a brand new randomly chosen unit will survive to time t_1 but fail before time t_2). It is worthy to note that the PDF *f(t)* has only non-negative values and eventually either becomes 0 as *t* increases or decreases towards the origin. Ideally, the CDF *F(t)* is monotonically increasing and goes from 0 to 1 as *t* approaches infinity. In other words, the total area under the curve is always 1.

A good example of a life distribution model is the 2-parameter Weibull distribution for *F(t)*. It has the CDF and PDF equations given by:

$$F(t) = 1 - e^{-\left(\frac{t}{\alpha}\right)^{\gamma}}, \quad f(t) = \frac{\gamma}{t}\left(\frac{t}{\alpha}\right)^{\gamma} e^{-\left(\frac{t}{\alpha}\right)^{\gamma}}$$

where γ is the "shape" parameter and α is a scale parameter called the characteristic life.

Survival is the complementary event to failure, and the reliability function, *R(t)*, also known as the survival function, *S(t)*, is defined by:

$R(t) = S(t) =$ the probability a unit survives beyond time *t*.

Since a unit either fails or survives, and one of these two mutually exclusive alternatives must occur, we have

$$R(t) = 1 - F(t), \quad F(t) = 1 - R(t)$$

Calculations using *R(t)* often occur when building up from single components to subsystems with many components. The reliability of a system is the product of the reliability functions of the components since both must survive in order for the system to survive. Building up to a "system" from the individual components is referred to as the "bottom-up" method. The bottom-up method is guided by the general rule: to calculate the reliability of a system of independent components, multiply the reliability functions of all the components.

Failure (or hazard) rate. The failure rate is the rate at which the population survivors at any given instant are "falling over the cliff," that is the failure rate is defined for non-repairable populations as the (instantaneous) rate of failure for the survivors to time *t* during the next instant of time. It is a rate per unit of time, and it represents a "snapshot" in time, since the next instant the failure rate may change and the units that have already failed play no further role since only the survivors count. The failure rate (or hazard rate) is denoted by *h(t)* and calculated from

$$h(t) = \frac{f(t)}{1-F(t)} = \frac{f(t)}{R(t)} = \text{the instantaneous (conditional) failure rate.}$$

The failure rate is sometimes called a "conditional failure rate" since the denominator 1 - *F(t)* (i.e., the population survivors) converts the expression into a conditional rate, given survival past some time, *t*. Since *h(t)* is equal to the negative of the derivative of ln{*R(t)*}, we have the useful identity:

$$F(t) = 1 - \exp\left\{-\int_0^t h(t)dt\right\}$$

If we let

$$H(t) = \int_0^t h(t)dt$$

be the cumulative hazard function, we then have $F(t) = 1 - e^{-H(t)}$. Two other useful identities that follow are:

$$h(t) = -\frac{d \ln R(t)}{dt}$$

$$H(t) = -\ln R(t).$$

A failure rate over any interval ($T_1 \rightarrow T_2$) characterizes an "average" failure rate for the interval and is denoted by $AFR(T_1,T_2)$. AFR's are calculated

$$AFR(T_2 - T_1) = \frac{\left(\int_{T_1}^{T_2} h(t)dt\right)}{T_2 - T_1} = \frac{H(T_2) - H(T_1)}{T_2 - T_1} = \frac{\ln R(T_1) - \ln R(T_2)}{T_2 - T_1}$$

$$AFR(0,T) = AFR(T) = \frac{H(T)}{T} = \frac{-\ln R(T)}{T}$$

Graphical depictions of failure rates: The "Bathtub curve." A plot of the failure rate over time yields a curve that looks like a drawing of a bathtub (at least to an engineer; Figure A1-8). If enough units from a given population are observed operating and failing over time, it is relatively easy to compute estimates of the failure rate *h(t)*.

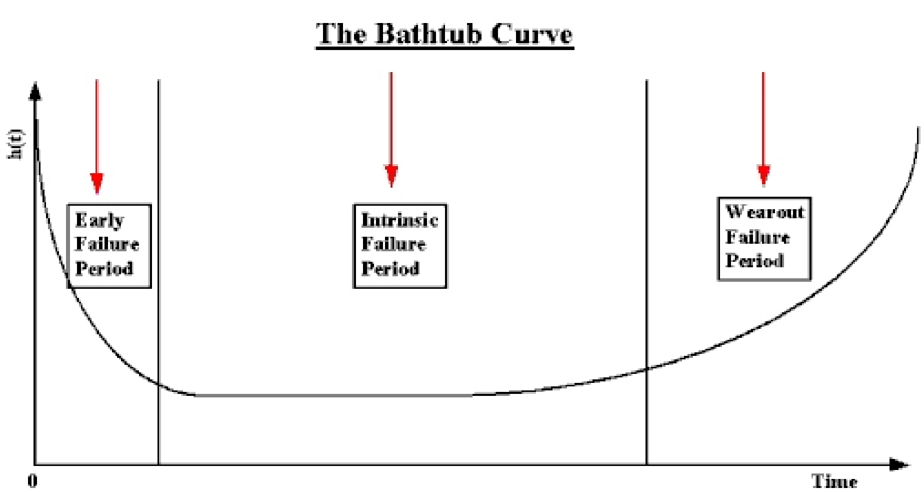

Figure A1-8. Typical "bathtub" curve of the reliability engineer.

In an idealized bathtub curve, the initial region begins at time zero (t_0) when a system's operation commences (which is analogous to birth in life table analysis). The system is initially characterized by a high but rapidly decreasing failure rate (e.g., early failure period for an engineering system, infant mortality period for biological populations and actuaries), with the decreasing failure rate typically lasting several weeks to a few months depending on the system. Following the initial, frequently transitory high failure rate, the failure rate levels off and remains roughly constant throughout "useful life of the system." This long period of a relative constant failure rate is known as the intrinsic failure period or the stable failure period. The constant failure rate level during this period is referred to as the intrinsic failure rate. Most systems function most of their lifetimes in this flat portion of the bathtub curve. If units from the population remain in use long enough, the failure rate begins to increase as materials wear out and degradation failures occur at an ever increasing rate. This is the "wearout failure period."

Based on empirical observations, the bathtub curve also applies to repairable systems, but in this instance, a "repair rate" or the "rate of occurrence of failures" (ROCOF) characterizes the ordinate of Figure A1-8. A different approach is used for modeling the repair rates for a repairable system, since failures occur at given system ages and the system, once repaired, be the same as new, or better, or worse than the original system. Frequency of repairs may be increasing, decreasing, or staying at a roughly constant rate, and may be characteristic of a given system.

Let $N(t)$ be a counting function that keeps track of the cumulative number of failures a given system has had from t_0, t_1, t_2,. . .t_n, t_{n+1}. Then, $N(t)$is a step function that jumps up one every time a failure occurs and stays at the new level until the next failure. Every system will have its own observed $N(t)$ function over time. If we observed the $N(t)$ curves for a large number of similar systems and "averaged" these curves, we would have an estimate of $M(t)$ = the expected number (average number) of cumulative failures by time t for these systems. Repair rate is the mean rate of failures per unit time, and the derivative of $M(t)$, denoted $m(t)$, is defined as the repair rate at time, t.

Parameter Types. Distributions can have any number of parameters, although as the number of parameters increases, so does the amount of data required for a good fit. In general, most lifetime distributions used for reliability and life data analysis are usually limited to a maximum of three parameters: the scale parameter, the shape parameter and the location parameter.

The scale parameter is the most common type of parameter. In distributions described by one-parameter, e.g., exponential distribution, the only parameter is the scale parameter. The scale parameter defines where the bulk of the distribution lies or how stretched out the distribution is. For the normal distribution, the scale parameter is the standard deviation. Not surprisingly, the shape parameter helps define the shape of a distribution. Some distributions such as the exponential or normal do not have a shape parameter, since they have a predefined shape that does not change, e.g., for the normal distribution, the shape is always the familiar bell shape. The effect of the shape parameter on a distribution is reflected in the range of shapes for the *PDF*, the reliability function, and the failure rate function. The location parameter, frequently denoted by γ, or *gamma* (γ), defines the location of the origin of a distribution and can be either positive or negative (Figure A1-9). In terms of lifetime distributions, the location parameter represents a time shift.

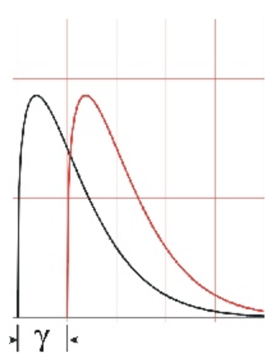

Figure A1-9. Directional shift dependent on γ.

The inclusion of a location parameter for a distribution whose domain is normally [0, ∞] will change the domain to [γ, ∞], where γ can be either positive or negative. The value of γ may have profound effects in terms of reliability, e.g., a positive location parameter indicates that the reliability for that particular distribution is always 100% up to γ. Given empirical observation, assuming that a system or a system component will absolutely not fail before any given time is highly unlikely; hence, almost all life distributions have a location parameter. In systems that have a history of high reliability, the location parameter is generally negligibly small. A negative location parameter suggests that failures theoretically occur before time zero (t_0), which reflects quiescent failures or those failures that occur prior to a product is being used. From a practical perspective, a negative location parameter reflects a failure in production quality, e.g., problems with the manufacturing, packaging or shipping processes, rather than an age-related failure. In reliability analysis the exponential and Weibull distributions most frequently employ the location parameter.

Lifetime distribution models. A handful of lifetime distribution models are commonly applied to investigations where data mining provides “starter sets” for an analysis. While empirical data sets developed as a direct result of observational or designed studies have contributed much to the literature for use in the current investigation focused on biota transfers, the inevitable stochastic character of the invasion process leads the analysis of risks to distribution models that have enjoyed great practical success in past investigations. There are a handful of distribution models that have successfully served as population models for lifetime distributions and failure times arising from a wide range of applications (e.g., engineering, biological, and ecological) and failure mechanisms. Sometimes there are probabilistic arguments based on the physics of the failure mode that tend to justify the choice of model. At other times the model is used solely because of its empirical success in fitting actual failure data. Six models frequently used are described in this appendix: Exponential, Weibull, Extreme Value, Lognormal, Gamma, and Proportional Hazards.

Exponential distribution. The exponential distribution is a commonly used distribution in reliability analysis and reliability engineering. Mathematically, it is a relatively simple distribution and is a special case of the Weibull distribution where β = 1. The exponential distribution is used to model the behavior of units that have a constant failure rate (or units that do not degrade with time or wear out).

While reliability theory initially developed outside a probabilistic and statistical setting, the disciplines have merged to yield a quantitative tool dependent on shared attributes such as statistical distributions. A statistical distribution is fully described by its probability density function (*PDF*), and a wide range of distributions exist that characterize processes and events occurring as part of those processes, e.g., the normal distribution is widely recognized and has a characteristic *PDF* reflected in its $f(t)$ (see Whittaker and Robinson 1967, Patel and Reed 1982, Evans et al. 2000). Some distributions better represent life data and are most commonly called lifetime distributions. One of the simplest and most commonly used life distributions is the exponential distribution, having a *PDF* characterized as

$$f(t) = \lambda e^{-\lambda t}$$

Here, t is a random variable for time, and the Greek letter λ (lambda) represents the parameter of the distribution. Depending on the value of λ, $f(t)$ will be scaled differently. For any distribution, the parameter or parameters of the distribution are estimated from data (experimental or observational). For example, the frequently encountered normal distribution is given by

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2}$$

where μ, the mean, and σ, the standard deviation, are its parameters. Both of these parameters are estimated from the data as the mean (m) and standard deviation (s) of the data. Once these parameters have been estimated, our function $f(t)$ is fully defined and any value for $f(t)$ can be calculated at given any value of t.

Given the mathematical representation of a distribution, we can also derive all of the functions needed for life data analysis, which will depend only on the value of t after the value of the distribution parameter or parameters have been estimated from data. For the exponential distribution, the exponential reliability function can be derived as

$$\begin{aligned} R(t) &= 1 - \int_0^t \lambda e^{-\lambda s} ds \\ &= 1 - [1 - e^{-\lambda \bullet t}] \\ &= e^{-\lambda \bullet t} \end{aligned}$$

The exponential failure rate function is

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{\lambda e^{-\lambda(t)}}{e^{-\lambda(t)}} = \lambda$$

and the exponential Mean-Time-To-Failure (MTTF) is given by:

$$\mu = \int_0^\infty t \cdot f(t)dt = \int_0^\infty t \cdot \lambda \cdot e^{-\lambda t}dt = \frac{1}{\lambda}$$

Given a distribution's *PDF*, similar derivations can be applied to any distribution with varying degrees of difficulty, depending on the complexity of $f(t)$.

Exponential Probability Density Function. The two-parameter exponential *PDF* is given by:

$$f(T) = \lambda e^{-\lambda(T-\gamma)},\ f(T) \geq 0,\ \lambda > 0,\ T \geq 0 \text{ or } \gamma$$

where or γ is the location parameter. If γ is positive, the distribution is shifted by a distance of γ to the right of the origin, signifying that the chance failures start to occur only after γ hours of operation and do not occur before this time. The scale parameter is

$$\frac{1}{\lambda} = \bar{T} - \gamma = m - \gamma$$

.

The exponential *PDF* has only one shape; hence, it has no shape parameter. The distribution starts at $T = \gamma$ at the level of $f(T = \gamma) = \lambda$ and decreases thereafter exponentially and monotonically as T increases beyond *g* and is convex. As $T \rightarrow \infty$, $f(T) \rightarrow 0$.

The One-Parameter Exponential Distribution. The one-parameter exponential *PDF* is obtained by setting γ = 0, and is given by:

$$f(T) = \lambda e^{-\lambda T} = \frac{1}{m} e^{-\frac{1}{m} T}$$

$$T \geq 0, \ \lambda > 0, \ m > 0$$

where:

$\lambda =$ constant failure rate, in failures per unit of measurement, *e.g.* failures per hour, per cycle, etc.,

$\lambda = \frac{1}{m}$,

$m =$ mean time between failures, or to a failure,

$T =$ operating time, life, or age, in hours, cycles, miles, actuations, etc.

This distribution requires only one parameter, λ, for its application. Characteristics of the one-parameter exponential distribution include: the location parameter, γ, is zero, and the scale parameter is 1/λ = *m*. As λ decreases, the distribution is stretched out to the right, and as λ is increased, the distribution is pushed toward the origin. As noted earlier in characterizing the two-parameter exponential distribution, this distribution has no shape parameter; hence, the exponential has a failure rate, λ. The distribution starts at *T* = 0 at the level of *f*(*T* = 0) = λ and decreases thereafter exponentially and monotonically as *T* increases, and is convex. And, as *T*→∞, *f*(*T*)→0. The *PDF* can be thought of as a special case of the Weibull *PDF* with γ = 0 and *b* = 1.

Exponential Statistical Properties. The mean, $\bar{T}$, or mean time to failure (MTTF) is given by:

$$\begin{aligned} \bar{T} &= \int_{\gamma}^{\infty} t \cdot f(t) dt \\ &= \int_{\gamma}^{\infty} t \cdot \lambda \cdot e^{-\lambda t} dt \\ &= \gamma + \frac{1}{\lambda} = m \end{aligned}$$

And, when γ = 0, the MTTF is the inverse of the exponential distribution's constant failure rate. This property is only true for the exponential distribution, since other distributions generally do not have a constant failure rate. As a consequence, the inverse relationship between failure rate and MTTF does not hold for other distributions.

The median, $\breve{T}$, is:

$$\breve{T} = \gamma + \frac{1}{\lambda} \cdot 0.693$$

and the mode, $\tilde{T}$, is:

$$\tilde{T} = \gamma$$

The standard deviation of the exponential distribution, s_T, is:

$$\sigma_T = \frac{1}{\lambda} = m$$

The Exponential Reliability Function. The equation for the two-parameter exponential cumulative density function, or *CDF* is given by:

$$F(T) = Q(T) = 1 - e^{-\lambda(T-\gamma)}$$

and, recalling that the reliability function of a distribution is simply one minus the *CDF*, the reliability function of the two-parameter exponential distribution is given by:

$$R(T) = 1 - Q(T) = 1 - \int_0^{T-\gamma} f(T)dT$$

$$R(T) = 1 - \int_0^{T-\gamma} \lambda e^{-\lambda T} dT = e^{-\lambda(T-\gamma)}$$

One-Parameter Exponential Reliability Function. The one-parameter exponential reliability function is given by:

$$R(T) = e^{-\lambda T} = e^{-\frac{T}{m}},$$

and the exponential conditional reliability equation, which characterizes the reliability for doing a task of *t* duration, having already successfully accumulated *T* hours of operation, is:

$$R(t|T) = \frac{R(T+t)}{R(T)} = \frac{e^{-\lambda(T+t-\gamma)}}{e^{-\lambda(T-\gamma)}} = e^{-\lambda t}$$

which says that the reliability for a "mission" of *t* duration undertaken after the component or equipment has already accumulated *T* hours of operation from age zero is only a function of the mission duration, not a function of the age at the beginning of the mission.

The Exponential Reliable Life. The reliable life, or the mission duration for a desired reliability goal, t_R, for the one-parameter exponential distribution is:

$$R(t_R) = e^{-\lambda(t_R-\gamma)}$$

$$\ln[R(t_R)] = -\lambda(t_R - \gamma)$$

or

$$t_R = \gamma - \frac{\ln[R(t_R)]}{\lambda}$$

The Exponential Failure Rate Function. The exponential failure rate function is:

$$\lambda(T) = \frac{f(T)}{R(T)} = \frac{\lambda e^{-\lambda(T-\gamma)}}{e^{-\lambda(T-\gamma)}} = \lambda = \text{constant}$$

As noted earlier, the constant failure rate is a characteristic of the exponential distribution, and only special cases of other distributions. Most distributions have failure rates that are functions of time.

Characteristics of the Exponential Distribution. The hallmarks of the exponential distribution is its constant failure rate and relatively simple mathematical form. The latter attribute makes the exponential easy to manipulate, and often times serves as a starting point in an analysis such at that completed in this investigation. With caution, the exponential distribution may be applied in preliminary evaluations of failure, then as systems are specified and empirical data gain increased resolution, alternative distributions such as the Weibull may be brought to the analysis.

The Effect of λ and γ on the Exponential *PDF*. The exponential *PDF* has only one shape; hence, no shape parameter is present. The function characterizing the exponential is always convex and is stretched to the right as it decreases in value. The value of the *PDF* function is always equal to the value of λ at $T = 0$ (or $T = \gamma$), and the location parameter, γ, if positive, shifts the beginning of the distribution by a distance of γ to the right of the origin, signifying that the chance of failures start only after γ hours of operation and not occur before. The scale parameter is $\frac{1}{\lambda} = \bar{T} - \gamma = m - \gamma$, and as $T \to \infty$, $f(T) \to 0$ (Figure A1-10).

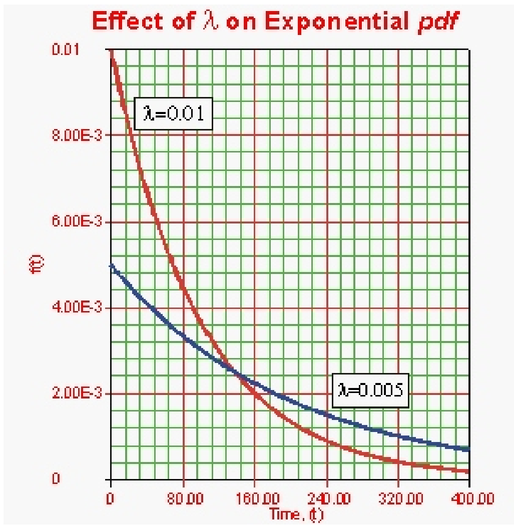

Figure A1-10. Effect of λ on exponential *PDF*.

The Effect of λ and γ on the Exponential Reliability Function. The one-parameter exponential reliability function starts at the value of 100% at $T = 0$, decreases thereafter monotonically and is convex (Figure A1-11). The two-parameter exponential reliability function remains at the value of 100% for $T = 0$ up to $T = \gamma$, then decreases monotonically thereafter and is convex. As $T \to \infty$, $R(T \to \infty) \to 0$. The reliability for mission duration, $T = m = (1/\lambda)$, or a mission duration of MTTF, is always equal to 0.368 or 36.8%, which means the reliability for a mission as long as one MTTF is relatively low.

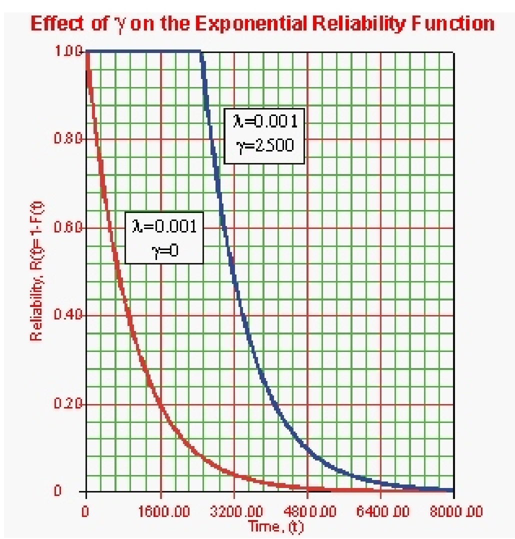

Figure A1-11. Effect of γ on exponential reliability function.

The exponential model with only one unknown parameter is the simplest of all distribution models. The key equations for the exponential distribution are listed below, with the failure rate reducing to the constant λ for any time. As a consequence, another name for the exponential mean is the "mean time to fail" (MTTF) = $1/\lambda$. The exponential distribution is the only distribution to have a constant failure rate. The Cummulative Hazard function for the exponential is just the integral of the failure rate or $H(t) = \lambda t$. The PDF and CDF for the exponential have the familiar shapes shown below (Figure A1-11 and Figure A1-12, respectively).

CDF: $F(t) = 1 - e^{-\lambda t}$

RELIABILITY: $R(t) = e^{-\lambda t}$

PDF: $f(t) = \lambda e^{-\lambda t}$

MEAN: $\frac{1}{\lambda}$

MEDIAN: $\frac{\ln 2}{\lambda} \cong \frac{.693}{\lambda}$

VARIANCE: $\frac{1}{\lambda^2}$

FAILURE RATE: $h(t) = \lambda$

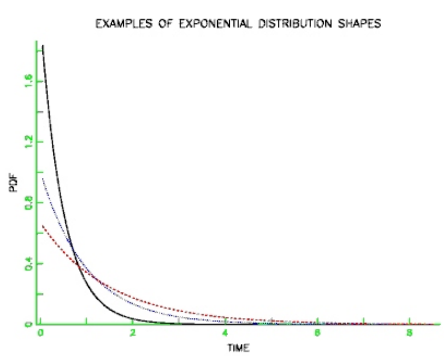

Figure A1-11. PDF for exponential distribution.

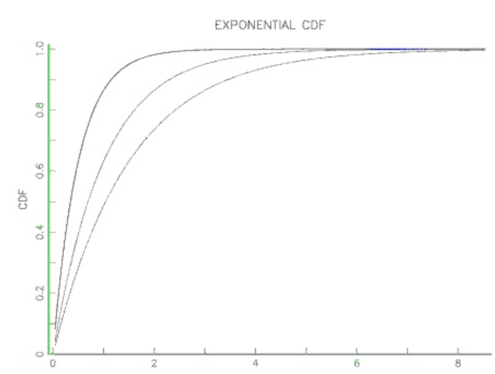

Figure A1-12. CDF for exponential distribution.

The exponential distribution models the flat portion of the bathtub curve, because of its constant failure rate property. Since most components and systems spend most of their lifetimes in this portion of the bathtub curve, this justifies frequent use of the exponential distribution when early failures or wear out is not a concern.

Weibull distribution. The Weibull distribution is one of the most widely used lifetime distributions in reliability analysis, and has proven versatile based on the value of its shape parameter, β. This brief background on the Weibull distribution applicable to the current preliminary investigation.

The Weibull distribution is a very flexible life distribution model with two parameters, and has CDF and PDF and other key formulas given by:

CDF: $F(t) = 1 - e^{-\left(\frac{t}{\alpha}\right)^{\gamma}}$

RELIABILITY: $e^{-\left(\frac{t}{\alpha}\right)^{\gamma}}$

PDF: $f(t) = \frac{\gamma}{t}\left(\frac{t}{\alpha}\right)^{\gamma} e^{-\left(\frac{t}{\alpha}\right)^{\gamma}}$

FAILURE RATE: $\frac{\gamma}{\alpha}\left(\frac{t}{\alpha}\right)^{\gamma-1}$

MEAN: $\alpha\Gamma\left(1+\frac{1}{\gamma}\right)$

MEDIAN: $\alpha(\ln 2)^{\frac{1}{\gamma}}$

VARIANCE: $\alpha^2\Gamma\left(1+\frac{2}{\gamma}\right) - \left[\alpha\Gamma\left(1+\frac{1}{\gamma}\right)\right]^2$

with α the scale parameter (the characteristic life), γ (gamma) the shape parameter, and Γ is the Gamma function with $\Gamma(N) = (N-1)!$ for integer N. The Cumulative Hazard function for the Weibull is the integral of the failure rate or

$$H(t) = \left(\frac{t}{\alpha}\right)^{\gamma}$$

A more general 3-parameter form of the Weibull includes an additional waiting time parameter μ (sometimes called a shift or location parameter). The formulas for the 3-parameter Weibull are easily obtained from the above formulas by replacing t by $(t - \mu)$ wherever t appears. No failure can occur before μ hours, so the time scale starts at μ, and not 0. If a shift parameter μ is known (based, perhaps, on the physics of the failure mode), then all you have to do is subtract μ from all the observed failure times and/or readout times and analyze the resulting shifted data with a 2-parameter Weibull. When $\gamma = 1$, the Weibull reduces to the exponential model , with $\alpha = 1/\lambda$ = the "mean time to fail" (MTTF). Depending on the value of the shape parameter λ , the

Weibull model can empirically fit a wide range of data histogram shapes as illustrated below (Figure A1-13).

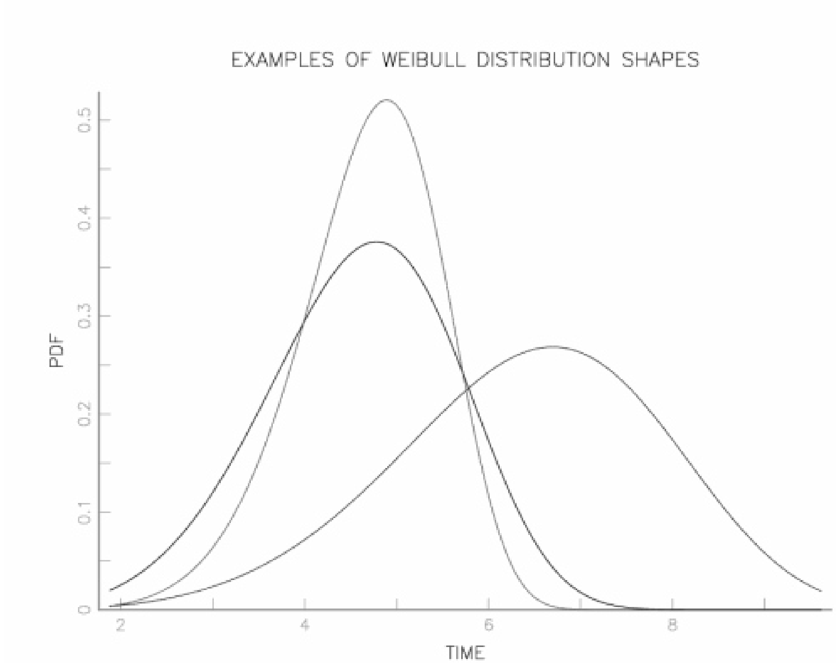

Figure 1A-13. Illustrations of Weibull distribution.

As a failure rate model, the Weibull is a natural extension of the constant failure rate exponential model since the Weibull has a polynomial failure rate with exponent (γ - 1). The Weibull has been applied to many failure analyses because of its flexible shape and ability to model a wide range of failure rates across a wide range of physical and biological systems.

Weibull Probability Density Function—The Three-Parameter Weibull Distribution. The three-parameter Weibull *PDF* is given by:

$$f(T) = \frac{\beta}{\eta}\left(\frac{T-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}}$$

where,

$$f(T) \geq 0,\ T \geq 0 \text{ or } \gamma,\ \beta > 0,\ \eta > 0,\ -\infty < \gamma < \infty,$$

and,

η = scale parameter,
β = shape parameter (or slope),
γ = location parameter.

The Two-Parameter Weibull Distribution. The two-parameter Weibull *PDF* is obtained by setting $\gamma = 0$ and is given by

$$f(T) = \frac{\beta}{\eta}\left(\frac{T}{\eta}\right)^{\beta-1} e^{-\left(\frac{T}{\eta}\right)^{\beta}}$$

The One-Parameter Weibull Distribution. The one-parameter Weibull *PDF* is obtained by again setting $\gamma = 0$ and assuming $\beta = C$, a constant or an assumed value such that

$$f(T) = \frac{C}{\eta}\left(\frac{T}{\eta}\right)^{C-1} e^{-\left(\frac{T}{\eta}\right)^{C}}$$

where the only unknown parameter is the scale parameter, η. In the one-parameter Weibull, we assume that the shape parameter β is known *a priori* from past experience on identical or similar products. The advantage of doing this is that data sets with few or no failures can be analyzed.

Weibull Statistical Properties. The mean, $\overline{T}$, (also called mean time to failure, *MTTF* or mean time between failures, *MTBF* by some authors) of the Weibull *PDF* is given by:

$$\overline{T} = \gamma + \eta \cdot \Gamma\left(\frac{1}{\beta} + 1\right)$$

where $\Gamma\left(\frac{1}{\beta} + 1\right)$ is the gamma function evaluated at the value of $\left(\frac{1}{\beta} + 1\right)$. The gamma function is defined as:

$$\Gamma(n) = \int_0^{\infty} e^{-x} x^{n-1} dx$$

For the two-parameter case, $\gamma = 0$, and

$$\overline{T} = \eta \cdot \Gamma\left(\frac{1}{\beta} + 1\right)$$

MTTF or MTBF equals η only when β = 1, since $\Gamma\left(\frac{1}{1} + 1\right) = \Gamma(2) = 1$.

The median of the Weibull distribution, $\breve{T}$, is given by:

$$\breve{T} = \gamma + \eta(\ln 2)^{\frac{1}{\beta}}$$

and the mode, $\tilde{T}$, by

$$\tilde{T} = \gamma + \eta\left(1 - \frac{1}{\beta}\right)^{\frac{1}{\beta}}.$$

The standard deviation of the Weibull distribution, s_T, is given by:

$$\sigma_T = \eta \cdot \sqrt{\Gamma\left(\frac{2}{\beta} + 1\right) - \Gamma\left(\frac{1}{\beta} + 1\right)^2}.$$

The Weibull Reliability Function. The equation for the three-parameter Weibull cumulative density function, *CDF*, is given by:

$$F(T) = 1 - e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}}$$

and the reliability function of the distribution is simply one minus the *CDF*; thus, the reliability function for the three-parameter Weibull distribution is given by:

$$R(T) = e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}}$$

The Weibull Conditional Reliability Function. The three-parameter Weibull conditional reliability function is given by:

$$R(t|T) = \frac{R(T+t)}{R(T)} = \frac{e^{-\left(\frac{T+t-\gamma}{\eta}\right)^{\beta}}}{e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}}}$$

or:

$$R(t|T) = e^{-\left[\left(\frac{T+t-\gamma}{\eta}\right)^{\beta}-\left(\frac{T-\gamma}{\eta}\right)^{\beta}\right]}$$

which characterizes the reliability for a new mission of t duration, having already accumulated T hours of operation up to the start of this new mission. If the units are checked to assure that they will start the next mission uneventfully, then the conditional reliability can be determined for the new mission based on the already accumulated T hours of uneventful operation.

The Weibull Reliable Life. The reliable life, T_R, of a unit for a specified reliability, starting the mission at age zero, is given by:

$$T_R = \gamma + \eta \cdot \{-\ln[R(T_R)]\}^{\frac{1}{\beta}}$$

This is the life for which the unit will be functioning successfully with a reliability of $R(T_R)$. If $R(T_R) = 0.50$, then $T_R = \breve{T}$, the median life, or the life by which half of the units will survive.

The Weibull Failure Rate Function. The Weibull failure rate function, $\lambda(T)$, is given by

$$\lambda(T) = \frac{f(T)}{R(T)} = \frac{\beta}{\eta}\left(\frac{T-\gamma}{\eta}\right)^{\beta-1}$$

Characteristics of the Weibull Distribution. As noted earlier, the Weibull distribution is widely used in reliability and life data analysis. Depending on the values of the parameters, the Weibull distribution can be used to model a variety of life behaviors, primarily due to the differential influences of model parameters that capture empirical data. Values of the shape parameter, β, and the scale parameter, η, affect such distribution characteristics as the shape of the *PDF* curve, the reliability and the failure rate, particularly when we focus on the general form of the Weibull distribution, the three-parameter form. The appropriate substitutions to obtain the other forms, such as the two-parameter form where $\gamma = 0$, or the one-parameter form where $\beta = C$ = constant, can easily be made.

Characteristic Effects of the Shape Parameter, β, for the Weibull Distribution. The Weibull shape parameter, β, is also known as the slope. This is because the value of β is equal to the slope of the regressed line in a probability plot. Different values of the shape parameter can have marked effects on the behavior of the distribution. In fact, some values of the shape parameter will cause the distribution equations to reduce to those of other distributions. For example, when $\beta = 1$, the *PDF* of the three-parameter Weibull reduces to that of the two-parameter exponential distribution or:

$$f(T) = \frac{1}{\eta} e^{-\frac{T-\gamma}{\eta}}$$

where $\frac{1}{\eta} = \lambda =$ failure rate. The parameter β is a pure number and is dimensionless.

The Effect of β on the *PDF*. Values of the shape parameter, β, alter the the shape of the Weibull distribution *PDF*, which can take on various forms based on the value of β (Figure A1-14).

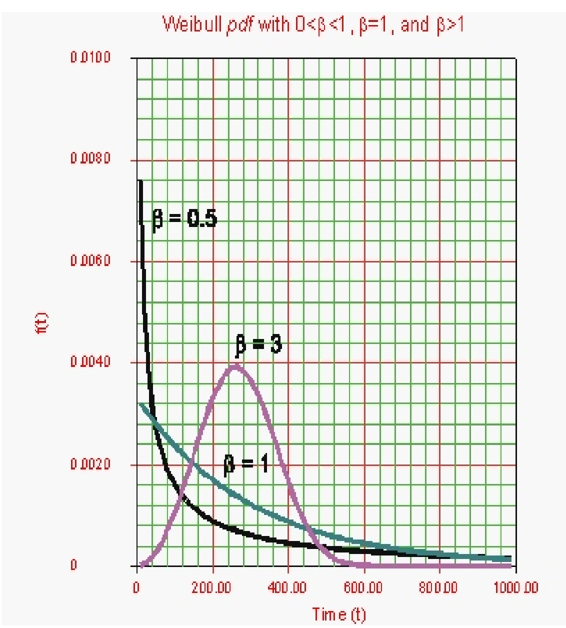

Figure A1-14. Three illustrations (*b*, or β = 0.5, 3.0, or 1.0) of the effect of the Weibull shape parameter on the *PDF*.

For $0 < \beta \leq 1$ (as illustrated by $\beta = 0.5$, and $\beta = 1.0$),

- As $T \to 0$ (or γ), $f(T) \to \infty$.
- As $T \to \infty$, $f(T) \to 0$.
- $f(T)$ decreases monotonically and is convex as T increases beyond the value of γ.
- The mode is non-existent.

For $\beta > 1$ (as illustrated by $\beta = 3$),

- $f(T) = 0$ at $T = 0$ (or γ).
- $f(T)$ increases as $T \to \tilde{T}$ (the mode), then decreases thereafter.
- For $\beta < 2.6$ the Weibull *PDF* is positively skewed (has a right tail), for $2.6 < \beta < 3.7$ its coefficient of skewness approaches zero (no tail). Consequently, it may approximate the normal *PDF*, and for $\beta > 3.7$ it is negatively skewed (left tail).

The value of β relates to the physical behavior of the items being modeled, and the available empirical data will influence the reliability and failure rate functions characterized in the analysis.

The Effect of β on the *CDF* and Reliability Function. The Weibull parameter β effects the *CDF* on a Weibull probability plot with a fixed value of η, as illustrated below (A1-15). Not

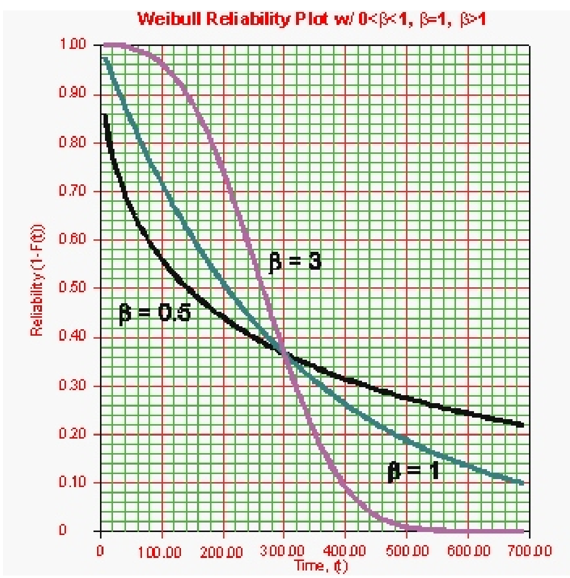

Figure A1-15. The effect of different values of β on the Weibull reliability plot.

surprisingly, the parameter is sometimes referred to as the slope. Note that the models represented by the three lines in the illustration below all have the same value of η, and demonstrate the effects of varied values of β on the reliability plot which is a linear analog of the probability plot. In general, $R(T)$ decreases sharply and monotonically for $0 < \beta < 1$ and is convex. For $\beta = 1$, $R(T)$ decreases monotonically but less sharply than for $0 < \beta < 1$ and is convex, while for $\beta > 1$, $R(T)$ decreases as T increases. As wear-out sets in, the curve goes through an inflection point and decreases sharply.

The Effect of β on the Weibull Failure Rate Function. The value of β has a marked effect on the failure rate of the Weibull distribution and inferences can be drawn about a population's failure characteristics just by considering whether the value of β is less than, equal to, or greater than one, as illustrated below (Figure A1-16).

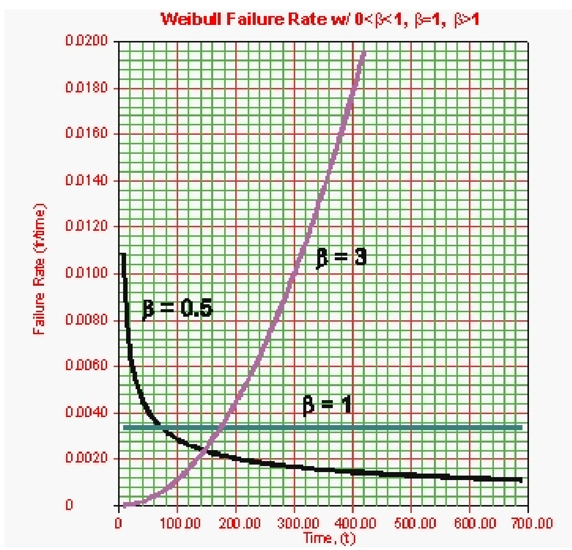

Figure A1-16. The effect of β on the Weibull failure rate function.

As suggested by the illustrations, populations with $\beta < 1$ exhibit a failure rate that decreases with time, populations with $\beta = 1$ have a constant failure rate (consistent with the exponential distribution) and populations with $\beta > 1$ have a failure rate that increases with time. All three life stages of the bathtub curve can be modeled with the Weibull distribution and varying values of β.

The Weibull failure rate for $0 < \beta < 1$ is unbounded at $T = 0$ (or γ). The failure rate, $\lambda(T)$, decreases thereafter monotonically and is convex, approaching the value of zero as $T \rightarrow \infty$ or when $\lambda(\infty) = 0$. This behavior makes it suitable for representing the failure rate of units exhibiting early-type failures, for which the failure rate decreases with age. When encountering such behavior in a manufactured product, it may be indicative of problems in the production process, inadequate burn-in, substandard parts and components, or problems with packaging and shipping.

For $\beta = 1$, $\lambda(T)$ yields a constant value of $\frac{1}{\eta}$ or:

$$\lambda(T) = \lambda = \frac{1}{\eta}$$

which makes it suitable for representing the failure rate of chance-type failures and the useful life period failure rate of units.

For $\beta > 1$, $\lambda(T)$ increases as T increases and becomes suitable for representing the failure rate of units exhibiting wear-out type failures. For $1 < \beta < 2$, the $\lambda(T)$ curve is concave, and the failure rate consequently increases at a decreasing rate as T increases.

For $\beta = 2$ there emerges a straight line relationship between $\lambda(T)$ and T, starting at $\lambda(T) = 0$ when $T = \gamma$, and increasing thereafter with a slope of $\frac{2}{\eta^2}$. Consequently, the failure rate increases at a constant rate as T increases. Furthermore, if $\eta = 1$, then the slope becomes equal to 2, and when $\gamma = 0$, $\lambda(T)$ becomes a straight line which passes through the origin with a slope of 2. When $\beta = 2$, the Weibull distribution equations reduce to that of the Rayleigh distribution (Balakrishvan and Nevzorov 2003, Evans et al. 2000). When $\beta > 2$, the $\lambda(T)$ curve is convex, with its slope increasing as T increases. Consequently, the failure rate increases at an increasing rate as T increases indicating wear-out life.

Characteristic Effects of the Scale Parameter, η, for the Weibull Distribution. A change in the scale parameter η has the same effect on the distribution as a change of the abscissa, e.g., increasing the value of η while holding β constant stretches out the *PDF* (Figure A1-17). Since the area under a *PDF* curve is a constant value of one, the "peak" of the *PDF* curve will decrease with the increase of η, as illustrated below. In general, if η increases while β and γ remain unchanged, then the distribution gets stretched out to the right and its height decreases; its shape and location remain unchanged, however. If η decreases while β and γ remain unchanged, then the distribution shifts to the left and approaches 0 or γ, depending on its value, and its height increases. As with T, the units of η are time, e.g., hours, miles, or cycles.

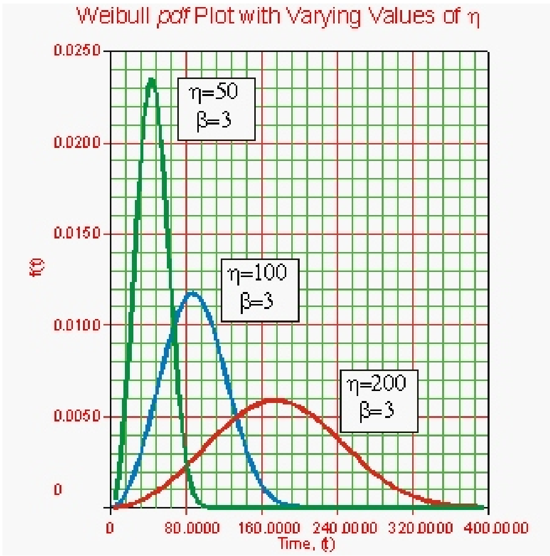

Figure A1-17. The effects of η on the Weibull *PDF* for a common *b*.

Characteristic Effects of the Location Parameter, γ, for the Weibull Distribution. The location parameter γ locates the distribution along the abscissa. Changing the value of γ slides the distribution and its associated function either to the right (if $\gamma > 0$) or to the left (if $\gamma < 0$). When $\gamma = 0$, the distribution starts at $T = 0$ or at the origin. If $\gamma > 0$, the distribution starts at location γ to the right of the origin, and if $\gamma < 0$, the distribution starts at location γ to the left of the origin. The location parameter provides an estimate of the earliest time-to-failure, and the life period 0 to + γ is a failure-free operating period of such units. The parameter γ may assume all values and provides an estimate of the earliest time a failure that may be observed. A negative γ may indicate that failures have occurred prior to the beginning of the test, namely during production, in storage, in transit, during checkout prior to the start of a mission, or prior to actual use. Given that γ affects the Weibull distribution along the abscissa, units for γ are the same as for *T*, e.g., hours, miles, or cycles.

Hazard function. MTBF assumes that the failure rate is constant for all intervals, yet the failure rate (λ) of a system may vary with time. By calculating the failure rate for smaller and smaller intervals of time, Δt, the interval becomes infinitely small and yields a hazard function which is the instantaneous failure rate at any point in time,

$$h(t) = \lim_{\Delta t \to 0} \frac{R(t) - R(t + \Delta t)}{\Delta t \cdot R(t)}$$

or,

$$h(t) = \frac{f(t)}{R(t)} \quad .$$

If the hazard function is constant, then the failure rate is the same for any equal period of time, which implies that failures occur with equal frequency during any equal period of time. While the exponential failure distribution has a constant failure rate, the Weibull distribution may be characterized by a hazard function that is not constant, but varies with time.

Extreme value distributions. Extreme value distributions are the limiting distributions for the minimum or the maximum of a very large collection of random observations from the same arbitrary distribution (see Castillo et al, 2005). Gumbel (1958) showed that for any well-behaved initial distribution (i.e., *F(x)* is continuous and has an inverse), only a few models are needed, depending on whether you are interested in the maximum or the minimum, and also if the observations are bounded above or below. In the context of reliability modeling, extreme value distributions for the minimum are frequently encountered, e.g., if a system consists of *n* identical components in series, and the system fails when the first of these components fails, then system failure times are the minimum of *n* random component failure times. Extreme value theory says that, independent of the choice of component model, the system model will approach a Weibull as *n* becomes large. The same reasoning can also be applied at a component level, if the component failure occurs when the first of many similar competing failure processes reaches a critical level.

The distribution often referred to as the extreme value distribution is the limiting distribution of the minimum of a large number of unbounded identically distributed random variables. The PDF and CDF are given by:

$$f(x) = \frac{1}{\beta} e^{\frac{x-\mu}{\beta}} e^{-e^{\frac{x-\mu}{\beta}}}, \quad -\infty < x < \infty, \beta > 0$$

$$F(x) = 1 - e^{-e^{\frac{x-\mu}{\beta}}}, \qquad -\infty < x < \infty, \beta > 0$$

If the *x* values are bounded below (as is the case with times of failure) then the limiting distribution is the Weibull. PDF shapes for the (minimum) extreme value distribution are illustrated in Figure A1-18.

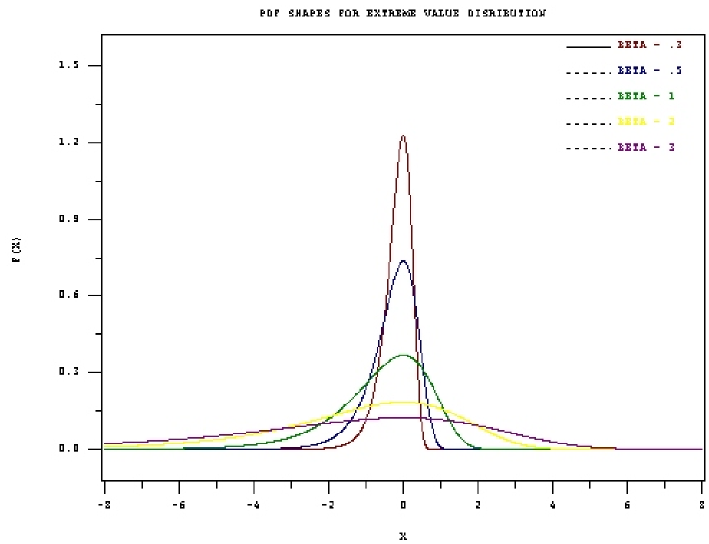

Figure A1-18. Illustrations of various Extreme Value distributions.

The Weibull distribution and the extreme value distribution have a useful mathematical relationship. If $t_1, t_2, ..., t_n$ are a sample of random times of failure from a Weibull distribution, then $\ln t_1$, $\ln t_2$, ...,$\ln t_n$ are random observations from the extreme value distribution. In other words, the natural log of a Weibull random time is an extreme value random observation. Because of this relationship, computer programs and graph papers designed for the extreme value distribution can be used to analyze Weibull data which is similar to using normal distribution programs to analyze lognormal data, after first taking natural logarithms of the data points.

Lognormal distribution. The lognormal life distribution, like the Weibull, is a very flexible model that can empirically fit many types of failure data. The two parameter form has parameters σ = the shape parameter and T_{50} = the median (a scale parameter). If time to failure, t_f, has a lognormal distribution, then the (natural) logarithm of time to failure has a normal distribution with mean $\mu = \ln T_{50}$ and standard deviation σ. This makes lognormal data convenient to work with; just take natural logarithms of all the failure times and censoring times and analyze the resulting normal data. Later on, convert back to real time and lognormal parameters using σ as the lognormal shape and $T_{50} = e^{\mu}$ as the (median) scale parameter. Below is a summary of the key formulas for the lognormal.

$$\text{PDF: } f(t) = \frac{1}{\sigma t \sqrt{2\pi}} e^{-\left(\frac{1}{2\sigma^2}\right)(\ln t - \ln T_{50})^2}$$

$$\text{CDF: } F(T) = \int_0^T \frac{1}{\sigma t \sqrt{2\pi}} e^{-\left(\frac{1}{2\sigma^2}\right)(\ln t - \ln T_{50})^2} dt = \Phi\left(\frac{\ln t - \ln T_{50}}{\sigma}\right)$$

with $\Phi(z)$ denoting the standard Normal CDF

$$\text{RELIABILITY: } R(T) = 1 - F(t)$$

$$\text{FAILURE RATE: } h(t) = \frac{f(t)}{R(t)}$$

$$\text{MEAN: } T_{50} e^{\frac{\sigma^2}{2}}$$

$$\text{MEDIAN: } T_{50}$$

$$\text{VARIANCE: } T_{50}^2 e^{\sigma^2}\left(e^{\sigma^2} - 1\right)$$

A more general 3-parameter form of the lognormal includes an additional waiting time parameter θ (sometimes called a shift or location parameter). The formulas for the 3-parameter lognormal are easily obtained from the above formulas by replacing *t* by (*t* - θ) wherever *t* appears. No failure can occur before θ hours, so the time scale starts at θ and not 0. If a shift parameter θ is known (based, perhaps, on the physics of the failure mode), then all you have to do is subtract θ from all the observed failure times and/or readout times and analyze the resulting shifted data with a 2-parameter lognormal.

Examples of lognormal PDF and failure rate plots are shown in Figure A1-19 and Figure A1-20, respectively. Lognormal shapes for small sigmas are very similar to Weibull shapes when the shape parameter γ is large and large sigmas give plots similar to small Weibull γ's. Both distributions are very flexible and it is often difficult to choose which to use based on empirical fits to small samples of (possibly censored) data.

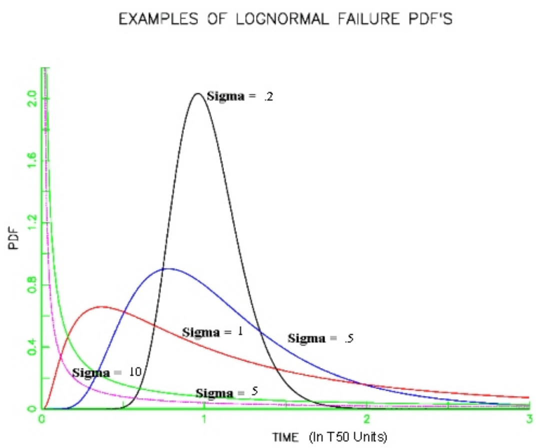

Figure A1-19. Illustrations of the lognormal distribution PDFs.

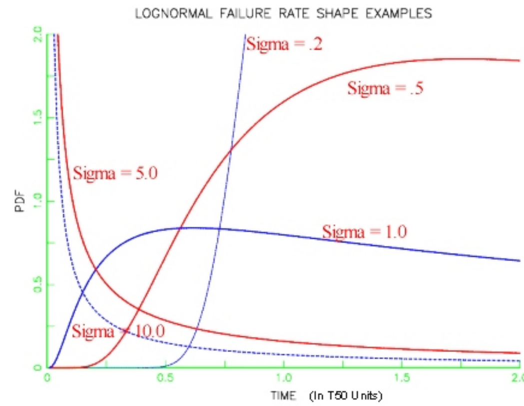

Figure A1-20. Illustrations of lognormal failure rates.

As suggested by the preceding plots, lognormal PDF and failure rate shapes are flexible enough to make the lognormal a very useful empirical model. Lognormal models can be theoretically derived under assumptions matching many common failure processes, which does not mean that the lognormal is always the correct model for these mechanisms, but it does perhaps explain why it has been empirically successful in so many cases.

Gamma distribution. In the literature, the gamma distribution is commonly presented in one of two forms, and different authors use different symbols for the shape and scale parameters. Below we show three ways of writing the gamma, with $a = \alpha = \gamma$, the "shape" parameter, and $b = 1/\beta$, the scale parameter. The exponential is a special case of the gamma when $a = 1$, the gamma reduces to an exponential distribution with $b = \lambda$. Another well-known statistical distribution, the Chi-Square, is also a special case of the gamma, where a Chi-Square distribution with n degrees of freedom is the same as a gamma with $a = n/2$ and $b = 0.5$ (or $\beta = 2$). Figure A1-21 illustrates of gamma PDFs, CDFs, and failure rate shapes.

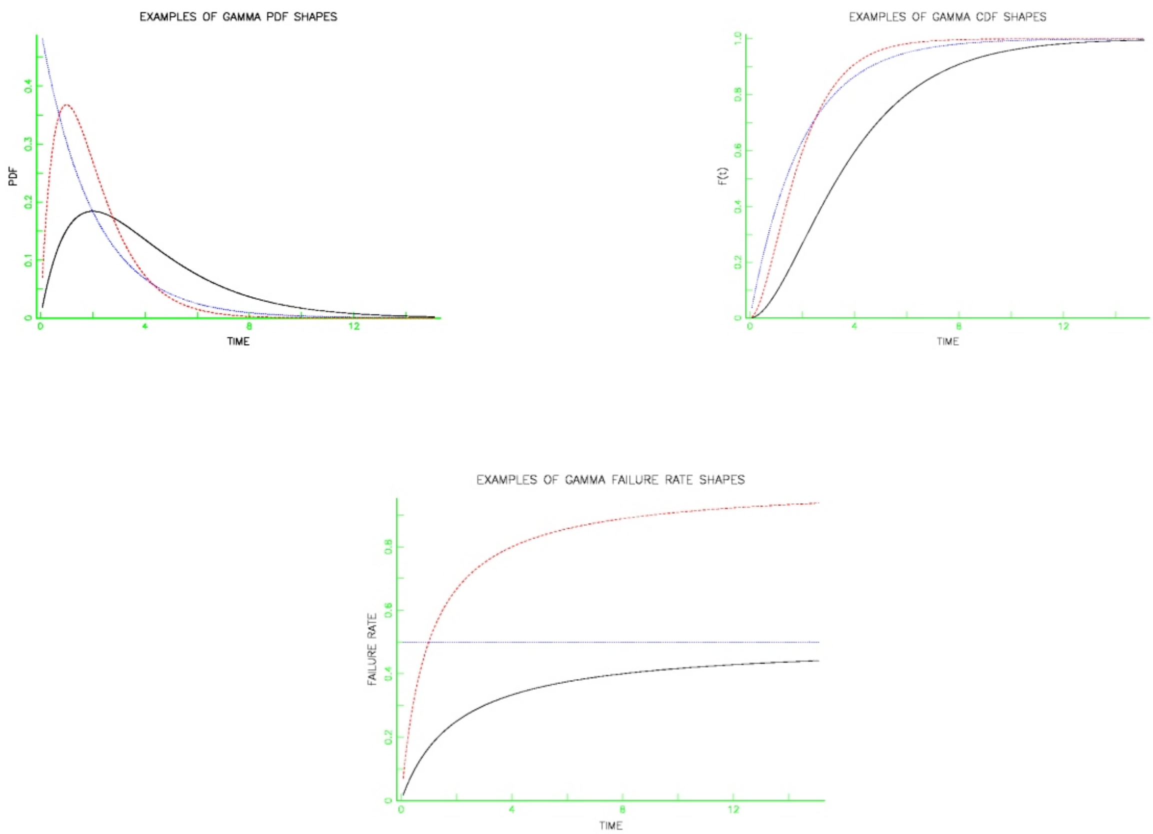

Figure A1-21. Illustrations of PDFs (top left), CDFs (top right), and failure rates (bottom) for gamma distribution.

The gamma distribution is commonly used for Bayesian reliability analysis, since it is a flexible life distribution model and frequently provides a good fit for failure data.

Proportional hazards model. The proportional hazards model is often used in survival analysis, but infrequently with engineering data. Cox's proportional hazards model (Cox 1972) has been used primarily to evaluate survival when secondary variables are likely exerting effects on the system. Its strength lies in its ability to model and test many inferences about survival without making any specific assumptions about the form of the life distribution model.

Proportional hazards model is based on an assumption that there are one or more explanatory variables (continuous, categorical, or binary) that affect lifetime. The hazard rate for a nominal (or baseline) set $z_0 = (x_0, y_0, \ldots)$ of these variables be given by $h_0(t)$, with $h_0(t)$ denoting legitimate hazard function (failure rate) for some unspecified life distribution model. The proportional hazard model assumes changing a stress variable (or explanatory variable) has the effect of multiplying the hazard rate by a constant. The proportional hazards model assumes we can write the changed hazard function for a new value of *z* as

$$h_z\,(t) = g(z)h_0\,(t)$$

In other words, changing *z*, the explanatory variable vector, results in a new hazard function that is proportional to the nominal hazard function, and the proportionality constant is a function of *z, g(z)*, independent of the time variable *t*. A common and useful form for *f(z)* is the log-linear model which has the equation: $g(x) = e^{ax}$ for one variable, $g(x,y) = e^{ax + by}$ for two variables.

The proportional hazards model is equivalent to the acceleration factor concept if and only if the life distribution model is a Weibull (which includes the exponential model, as a special case). For a Weibull with shape parameter γ, and an acceleration factor *AF* between nominal use fail time t_0 and high stress fail time t_s (with $t_0 = AFt_s$) we have $g(s) = AF^{\gamma}$. In other words, $h_s(t) = \gamma_{AFh0}(t)$. Under a log-linear model assumption for *g(z)* without any further assumptions about the life distribution model, it is possible to analyze experimental data and compute maximum likelihood estimates and use likelihood ratio tests to determine which explanatory variables are highly significant. More details on the theory and applications of the proportional hazards model may be found in Kalbfleisch and Prentice (2002) and Lawless (2003).

Data limitations and failure analysis. The more reliable a system is, the more difficult it is to gather failure data to predict its failure. Two closely related problems that are typical of reliability data. First, data are generally censored (e.g., when an observation period ends, but not all units have failed). Failure data may be "right censored" or "left censored," depending on the way the data were collected (e.g., testing period of fixed time or fixed number of failures defines testing period, respectively; see Kalbfleisch and Prentice (2002), Lawless (2003), and Meeker and Escobar (1998) for a comprehensive review of the role of data censoring in limiting failure analysis). Data may also be "multicensored," since different studies may record observations differently for identical systems being considered, e.g., failure may be identified as a run-time endpoint, if the unit did not fail while under observation, or failure may be identified as an exact failure time, or failure may be identified as an interval of time during which the unit failed. Many statistical methods can be used to fit models and estimate failure rates even with censored data (e.g., probability plotting, maximum likelihood estimation; see Meeker and Escobar 1998).

Second, observed failures may be few in number or completely absent, if the system is highly reliable or inadequately sampled. Independently or in combination, these data limitations influence the uncertainty associated with analyzing failure data, particularly as those tools apply to evaluations for risk. Although serving as sources of uncertainty, solutions to these data limitations generally mean making additional assumptions in developing risk scenarios and using "best guess" models for characterizing failure events and their role in modifying risks (e.g., increasing or decreasing risk estimates).

Distinguishing Failure Modes. Failures are a generally a coarse measurement of system malfunction, and may result from several different failure modes (e.g., root cause of failure may differ from one occurrence to the next), and in the current investigation the discrimination between failure modes are oversimplified as tranmission system-related (e.g., failure of pumps, valves, gates, or pipe) or treatment-related (e.g., failure in UV disinfection or microfiltration), which may be considered within the context of competing risks.

In general, the analysis of competing risks revolves about failure mechanisms that are assumed to be independent, with the first "failure mode" that occurs causes the system to fail. For example, if a species invasion is considered a failure, then each of k different failure modes or ways a failure can occur are competing, and underlying each failure mode is a failure mechanism (for a given pathway, each mode will have one to many different failure mechanisms).

In evaluating competing risks, a system's reliability is considered as a "build up" model, based on evaluations of the reliability of each failure mode. Three assumptions are generally specified in such an analysis of competing risks: (1) each failure mechanism leading to a particular type of failure (i.e., failure mode) proceeds independently of every other one at least until a failure occurs; (2) a failure event occurs when the first of all the competing failure mechanisms reaches a failed state; and (3) each of the k failure modes has a known life distribution model $F_i(t)$.

Quantitatively, the competing risk model is best applied when all three assumptions hold. If $R_c(t)$, $F_c(t)$, and $h_c(t)$ denote the reliability, CDF and failure rate for the component, respectively, and $R_i(t)$, $F_i(t)$and $h_i(t)$ are the reliability, CDF and failure rate for the i-th failure mode, respectively, then the competing risk model formulas are:

$$R_c(t) = \prod_{i=1}^{k} R_i(t)$$

$$F_c(t) = 1 - \prod_{i=1}^{k} \{1 - F_i(t)\}$$

$$h_c(t) = \sum_{i=1}^{k} h_i(t)$$

Multiply reliabilities and add failure rates. For evaluating competing risks, consider all failure mechanisms are racing to see which can reach failure first, e.g., which competing risk is most likely to yield a species invasion. If the failure mechanisms are assumed independent, then the component reliability is the product of the failure mode reliabilities and the component failure rate is the sum of the failure rates. This algorithm holds for any arbitrary life distribution model, as long as "independence" and "first mechanism failure causes the component to fail" assumptions are not violated. Alternative "rules" associated with calculating risks for different types of systems are briefly reviewed below.

Failures in series models. The series model is used to go from individual components to the entire system, assuming the system fails when the first component fails and all components fail or survive independently of one another. The series model is a "build up" model where components are constructed to yield sub-assemblies and systems, and only applies to non-replaceable populations (or first failures of populations of systems). The assumptions and formulas for the series model are identical to those for the competing risk model, with the *k* failure modes within a component replaced by the *n* components within a system. In Figure A1-22, the entire system has *n* components in series, and the system operates when all components function or fails when at least one component fails. Each component is independent, but failure in one component means the system fails. Simplified, a system of 5 components in series may be represented by an equivalent system (as far as reliability is concerned) with only one component.

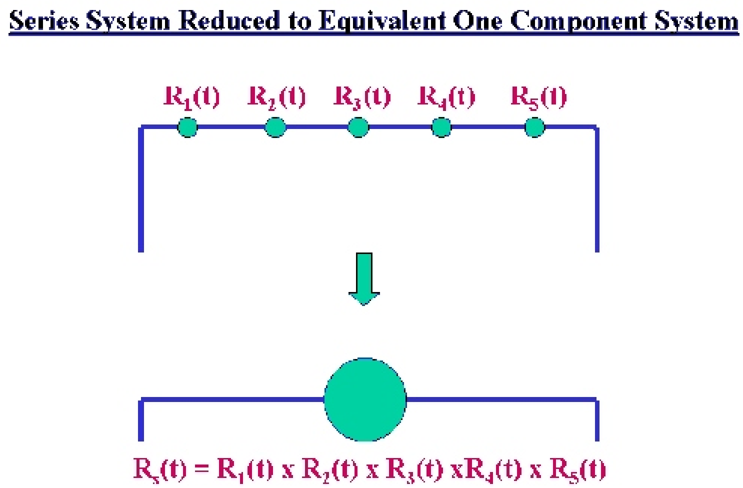

Figure A1-22. Illustration of a series system.

Failures in parallel or redundant systems. In parallel systems, all *n* components that make up the system operate independently and the system works as long as at least one component still works. Parallel systems are the opposite of a system operating in series in which the first component failure causes the system to fail. In a parallel system, all the components have to fail before the system fails. If there are *n* components, any (n-1) of them may be considered redundant to the remaining one (even if the components are all different). When the system is turned on, all the components operate until they fail. The system fails at the time of the last component failure.

In contrast to a system operating in series, the assumptions for a parallel model are: (1) all components operate independently of one another, as far as reliability is concerned; (2) the system operates as long as at least one component is still operating, and system failure only occurs at the time of the last component failure; and (3) the CDF for each component is known. For a system operating in parallel, the CDF $F_s(t)$ for the system is just the product of the CDF's $F_i(t)$ for the components or

$$F_s(t) = \prod_{i=1}^{n} F_i(t)$$

$R_s(t)$ and $h_s(t)$ can be evaluated using basic definitions, once we have $F_s(t)$. Figure A1-23 represents a parallel system with 5 components and the (reliability) equivalent 1 component system with a CDF F_s equal to the product of 5 component CDFs.

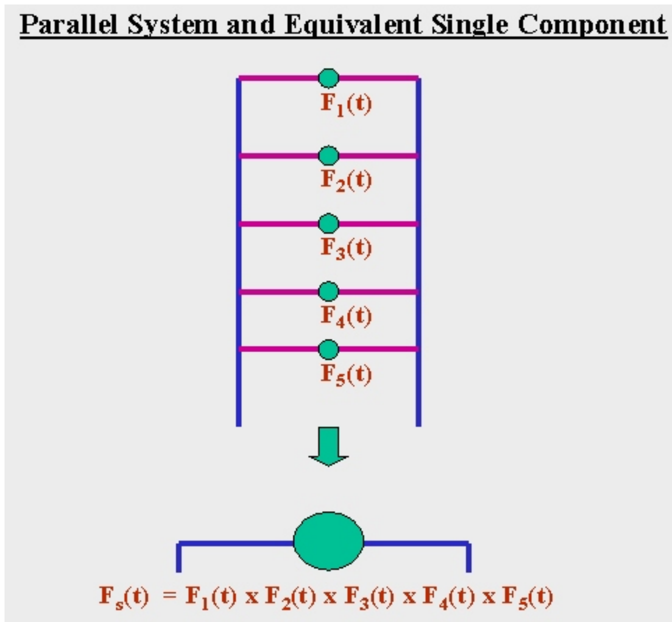

Figure A1-23. An illustration of a parallel system.

R out of N model. An "*r* out of *n*" system survives when at least *r* of its components are working (any *r*). An "*r* out of *n*" system contains includes the series system and the parallel system as special cases. The system has *n* components that operate or fail independently of one another and as long as at least *r* of these components (any *r*) survive, the system survives. System failure occurs when the [*n* - (*r* +1)] component failure occurs. When $r = n$, the *r* out of *n* model reduces to the series model, and when $r = 1$, the *r* out of *n* model becomes the parallel model. When all the components of the system (1) are identical and have the identical reliability function *R(t)*; (2) operate independently of one another (as far as failure is concerned); (3) the system can survive any (*n-r*) of the components failing, but fails upon the [(*n* - (*r+1*)] component failure, then system reliability is given by adding the probability of exactly *r* components surviving to time *t* to the probability of exactly (*r+1*) components surviving, and so on up to the probability of all components surviving to time *t*. These are binomial probabilities (with $p = R(t)$), so the system reliability is given by:

$$R_s(t) = \sum_{i=r}^{n} \binom{n}{i} [R(t)]^i [1 - R(t)]^{n-i}$$

If all the components are not identical, then $R_s(t)$ would be the sum of probabilities evaluated for all possible terms that could be formed by picking at least r survivors and the corresponding failures. The probability for each term is evaluated as a product of $R(t)$'s and $F(t)$'s. For example, for $n = 4$ and $r = 2$, the system reliability would be (abbreviating the notation for $R(t)$ and $F(t)$ by using only R and F)

$$\begin{aligned} R_s = \; & R_1R_2F_3F_4 + R_1R_3F_2F_4 + R_1R_4F_2F_3 + R_2R_3F_1F_4 + R_2R_4F_1F_3 + R_3R_4F_1F2 \\ & + R_1R_2R_3F_4 + R_1R_3R_4F_2 + R_1R_2R_4F_3 + R_2R_3R_4F_1 + R_1R_2R_3R_4 \end{aligned}$$

Complex systems. For complex systems, reliability can be evaluated by successive applications of series and parallel models. Many complex systems can be diagramed as combinations of series components, parallel components, and *R* out of *N* components (see, e.g., Miller and Escobar 1998; Thompson 2000; Borgelt and Kruse 2002; Huzurbazar 2005; Banerjee et al 2004; Salthe 1985; Puccia and Levins 1985). While many engineering analyses, and indeed many evaluations of ecological systems, seek to reduce their complexity to "equivalent" simple systems, many systems with marked interdependence and interconnectedness, or with systems characterized by complicated operational logic structure, alternative tools such as event trees, Boolean representations, coherent structures, cut sets and decompositions may be involved. The reader is referred to those authors listed above for more comprehensive treatment of complex systems analysis[1].

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[1] Graphics and excerpts from NIST/SEMATECH (2004), e-Handbook of Statistical Methods (available at http://www.itl.nist.gov/div898/handbook/) have been relied upon for peer-reviewed technical summaries incorporated into this overview of reliability analysis in this appendix.

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Appendix 2A. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Summary of Results

Section 1 Offsetting Restoration for One Organism

Section 1.1 Lake Ashtabula - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (Acres)	Fast Invasion (Acres)
Very Low	1.00E-09	87.0%	0.00000632	0.00000792
Low	1.00E-06	7.6%	0.00632	0.00792
Moderate	1.00E-03	3.7%	6.32	7.92
High	1.00E-02	1.7%	63.2	79.2
Very High	1.00E+00	0.0%	6,320	7,920
Weighted Average (a)			1.31	1.64

Section 1.2 Lake Ashtabula - Jump Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (Acres)	Fast Invasion (Acres)
Very Low	1.00E-09	87.0%	0.00000716	0.00000816
Low	1.00E-06	7.6%	0.00716	0.00816
Moderate	1.00E-03	3.7%	7.16	8.16
High	1.00E-02	1.7%	71.6	81.6
Very High	1.00E+00	0.0%	7,160	8,160
Weighted Average (a)			1.48	1.69

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (River-Miles)	Fast Invasion (River-Miles)
Very Low	1.00E-09	87.0%	0.0000000801	0.000000303
Low	1.00E-06	7.6%	0.0000801	0.000303
Moderate	1.00E-03	3.7%	0.0801	0.303
High	1.00E-02	1.7%	0.801	3.03
Very High	1.00E+00	0.0%	80.1	303
Weighted Average (a)			0.02	0.06

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (River-Miles)	Fast Invasion (River-Miles)
Very Low	1.00E-09	87.0%	0.0000000486	0.000000317
Low	1.00E-06	7.6%	0.0000486	0.000317
Moderate	1.00E-03	3.7%	0.0486	0.317
High	1.00E-02	1.7%	0.486	3.17
Very High	1.00E+00	0.0%	48.6	317
Weighted Average (a)			0.01	0.07

Section 1.5 Lower Sheyenne River - Jump Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (River-Miles)	Fast Invasion (River-Miles)
Very Low	1.00E-09	87.0%	0.0000000803	0.000000326
Low	1.00E-06	7.6%	0.0000803	0.000326
Moderate	1.00E-03	3.7%	0.0803	0.326
High	1.00E-02	1.7%	0.803	3.26
Very High	1.00E+00	0.0%	80.3	326
Weighted Average (a)			0.02	0.07

Section 2 Offsetting Restoration for 31 Biota

Section 2.1 Slow Invasion

Dispersal Scenario for the Lower Sheyenne River and Lake Ashtabula	<----Offsetting Restoration for 31 Biota (b)----> Sheyenne River (River-Miles)	Lake Ashtabula (Acres)
0 Jump - 31 Progressive	0.9	40.6
1 Jump - 30 Progressive	0.9	40.8
10 Jump - 21 Progressive	1.0	42.3

Section 2.2 Fast Invasion

Dispersal Scenario for the Lower Sheyenne River and Lake Ashtabula	<----Offsetting Restoration for 31 Biota (b)----> Sheyenne River (River-Miles)	Lake Ashtabula (Acres)
0 Jump - 31 Progressive	4.0	50.8
1 Jump - 30 Progressive	4.0	50.9
10 Jump - 21 Progressive	4.0	51.3

Section 3 Notes

(a) Weighted by the percent outcomes of respective risk categories

(b) Multiples of the weighted averages of the respective offsetting restoration levels for one organism, combined according to the dispersal scenarios for the Lower Sheyenne River and Lake Ashtabula

Appendix 2B. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Slow Invasion - Very Low Risk (One Organism)

Probability of successful invasion:	1.00E-09
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.0000000000	0.0000000000
1	5.88%	0.00000000588%	0.0000003079	0.0000002989
2	11.76%	0.00000001176%	0.0000006158	0.0000005804
3	17.65%	0.00000001765%	0.0000009236	0.0000008453
4	23.53%	0.00000002353%	0.0000012315	0.0000010942
5	29.41%	0.00000002941%	0.0000015394	0.0000013279
6	35.29%	0.00000003529%	0.0000018473	0.0000015471
7	41.18%	0.00000004118%	0.0000021552	0.0000017524
8	47.06%	0.00000004706%	0.0000024631	0.0000019444
9	52.94%	0.00000005294%	0.0000027709	0.0000021237
10	58.82%	0.00000005882%	0.0000030788	0.0000022909
11	64.71%	0.00000006471%	0.0000033867	0.0000024466
12	70.59%	0.00000007059%	0.0000036946	0.0000025913
13	76.47%	0.00000007647%	0.0000040025	0.0000027255
14	82.35%	0.00000008235%	0.0000043104	0.0000028497
15	88.24%	0.00000008824%	0.0000046182	0.0000029643
16	94.12%	0.00000009412%	0.0000049261	0.0000030698
17	100.00%	0.00000010000%	0.0000052340	0.0000031667
Beyond (c)				0.0001055552
Total				0.0001391741

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.0000000000	0.0000000000
1	12.50%	0.00000001250%	0.0000006543	0.0000006352

2	25.00%	0.00000002500%	0.0000013085	0.0000012334
3	37.50%	0.00000003750%	0.0000019628	0.0000017962
4	50.00%	0.00000005000%	0.0000026170	0.0000023252
5	62.50%	0.00000006250%	0.0000032713	0.0000028218
6	75.00%	0.00000007500%	0.0000039255	0.0000032875
7	87.50%	0.00000008750%	0.0000045798	0.0000037238
8	100.00%	0.00000010000%	0.0000052340	0.0000041318
Beyond (d)				0.0001377256
Total				0.0001576804

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.0000000000	0.0000000000
1	0.64%	0.00000000064%	0.0000000016	0.0000000015
2	1.27%	0.00000000127%	0.0000000031	0.0000000029
3	1.91%	0.00000000191%	0.0000000047	0.0000000043
4	2.55%	0.00000000255%	0.0000000062	0.0000000055
5	3.18%	0.00000000318%	0.0000000078	0.0000000067
6	3.82%	0.00000000382%	0.0000000093	0.0000000078
7	4.46%	0.00000000446%	0.0000000109	0.0000000089
8	5.10%	0.00000000510%	0.0000000125	0.0000000098
9	5.73%	0.00000000573%	0.0000000140	0.0000000107
10	6.37%	0.00000000637%	0.0000000156	0.0000000116
11	7.01%	0.00000000701%	0.0000000171	0.0000000124
12	7.64%	0.00000000764%	0.0000000187	0.0000000131
13	8.28%	0.00000000828%	0.0000000202	0.0000000138
14	8.92%	0.00000000892%	0.0000000218	0.0000000144
15	9.55%	0.00000000955%	0.0000000234	0.0000000150
16	10.19%	0.00000001019%	0.0000000249	0.0000000155
17	10.83%	0.00000001083%	0.0000000265	0.0000000160
18	11.46%	0.00000001146%	0.0000000280	0.0000000165
19	12.10%	0.00000001210%	0.0000000296	0.0000000169
20	12.74%	0.00000001274%	0.0000000311	0.0000000172
21	13.38%	0.00000001338%	0.0000000327	0.0000000176
22	14.01%	0.00000001401%	0.0000000343	0.0000000179
23	14.65%	0.00000001465%	0.0000000358	0.0000000181
24	15.29%	0.00000001529%	0.0000000374	0.0000000184
25	15.92%	0.00000001592%	0.0000000389	0.0000000186
26	16.56%	0.00000001656%	0.0000000405	0.0000000188
27	17.20%	0.00000001720%	0.0000000420	0.0000000189
28	17.83%	0.00000001783%	0.0000000436	0.0000000191
29	18.47%	0.00000001847%	0.0000000452	0.0000000192
30	19.11%	0.00000001911%	0.0000000467	0.0000000192
31	19.75%	0.00000001975%	0.0000000483	0.0000000193
32	20.38%	0.00000002038%	0.0000000498	0.0000000194
33	21.02%	0.00000002102%	0.0000000514	0.0000000194

34	21.66%	0.00000002166%	0.0000000529	0.0000000194
35	22.29%	0.00000002229%	0.0000000545	0.0000000194
36	22.93%	0.00000002293%	0.0000000561	0.0000000193
37	23.57%	0.00000002357%	0.0000000576	0.0000000193
38	24.20%	0.00000002420%	0.0000000592	0.0000000192
39	24.84%	0.00000002484%	0.0000000607	0.0000000192
40	25.48%	0.00000002548%	0.0000000623	0.0000000191
41	26.11%	0.00000002611%	0.0000000639	0.0000000190
42	26.75%	0.00000002675%	0.0000000654	0.0000000189
43	27.39%	0.00000002739%	0.0000000670	0.0000000188
44	28.03%	0.00000002803%	0.0000000685	0.0000000187
45	28.66%	0.00000002866%	0.0000000701	0.0000000185
46	29.30%	0.00000002930%	0.0000000716	0.0000000184
47	29.94%	0.00000002994%	0.0000000732	0.0000000182
48	30.57%	0.00000003057%	0.0000000748	0.0000000181
49	31.21%	0.00000003121%	0.0000000763	0.0000000179
50	31.85%	0.00000003185%	0.0000000779	0.0000000178
51	32.48%	0.00000003248%	0.0000000794	0.0000000176
52	33.12%	0.00000003312%	0.0000000810	0.0000000174
53	33.76%	0.00000003376%	0.0000000825	0.0000000172
54	34.39%	0.00000003439%	0.0000000841	0.0000000170
55	35.03%	0.00000003503%	0.0000000857	0.0000000169
56	35.67%	0.00000003567%	0.0000000872	0.0000000167
57	36.31%	0.00000003631%	0.0000000888	0.0000000165
58	36.94%	0.00000003694%	0.0000000903	0.0000000163
59	37.58%	0.00000003758%	0.0000000919	0.0000000161
60	38.22%	0.00000003822%	0.0000000934	0.0000000159
61	38.85%	0.00000003885%	0.0000000950	0.0000000157
62	39.49%	0.00000003949%	0.0000000966	0.0000000154
63	40.13%	0.00000004013%	0.0000000981	0.0000000152
64	40.76%	0.00000004076%	0.0000000997	0.0000000150
65	41.40%	0.00000004140%	0.0000001012	0.0000000148
66	42.04%	0.00000004204%	0.0000001028	0.0000000146
67	42.68%	0.00000004268%	0.0000001043	0.0000000144
68	43.31%	0.00000004331%	0.0000001059	0.0000000142
69	43.95%	0.00000004395%	0.0000001075	0.0000000140
70	44.59%	0.00000004459%	0.0000001090	0.0000000138
71	45.22%	0.00000004522%	0.0000001106	0.0000000136
72	45.86%	0.00000004586%	0.0000001121	0.0000000133
73	46.50%	0.00000004650%	0.0000001137	0.0000000131
74	47.13%	0.00000004713%	0.0000001152	0.0000000129
75	47.77%	0.00000004777%	0.0000001168	0.0000000127
76	48.41%	0.00000004841%	0.0000001184	0.0000000125
77	49.04%	0.00000004904%	0.0000001199	0.0000000123
78	49.68%	0.00000004968%	0.0000001215	0.0000000121
79	50.32%	0.00000005032%	0.0000001230	0.0000000119
80	50.96%	0.00000005096%	0.0000001246	0.0000000117
81	51.59%	0.00000005159%	0.0000001261	0.0000000115
82	52.23%	0.00000005223%	0.0000001277	0.0000000113
83	52.87%	0.00000005287%	0.0000001293	0.0000000111
84	53.50%	0.00000005350%	0.0000001308	0.0000000109
85	54.14%	0.00000005414%	0.0000001324	0.0000000107

86	54.78%	0.00000005478%	0.0000001339	0.0000000105
87	55.41%	0.00000005541%	0.0000001355	0.0000000104
88	56.05%	0.00000005605%	0.0000001370	0.0000000102
89	56.69%	0.00000005669%	0.0000001386	0.0000000100
90	57.32%	0.00000005732%	0.0000001402	0.0000000098
91	57.96%	0.00000005796%	0.0000001417	0.0000000096
92	58.60%	0.00000005860%	0.0000001433	0.0000000094
93	59.24%	0.00000005924%	0.0000001448	0.0000000093
94	59.87%	0.00000005987%	0.0000001464	0.0000000091
95	60.51%	0.00000006051%	0.0000001479	0.0000000089
96	61.15%	0.00000006115%	0.0000001495	0.0000000088
97	61.78%	0.00000006178%	0.0000001511	0.0000000086
98	62.42%	0.00000006242%	0.0000001526	0.0000000084
99	63.06%	0.00000006306%	0.0000001542	0.0000000083
100	63.69%	0.00000006369%	0.0000001557	0.0000000081
101	64.33%	0.00000006433%	0.0000001573	0.0000000079
102	64.97%	0.00000006497%	0.0000001588	0.0000000078
103	65.61%	0.00000006561%	0.0000001604	0.0000000076
104	66.24%	0.00000006624%	0.0000001620	0.0000000075
105	66.88%	0.00000006688%	0.0000001635	0.0000000073
106	67.52%	0.00000006752%	0.0000001651	0.0000000072
107	68.15%	0.00000006815%	0.0000001666	0.0000000070
108	68.79%	0.00000006879%	0.0000001682	0.0000000069
109	69.43%	0.00000006943%	0.0000001697	0.0000000068
110	70.06%	0.00000007006%	0.0000001713	0.0000000066
111	70.70%	0.00000007070%	0.0000001729	0.0000000065
112	71.34%	0.00000007134%	0.0000001744	0.0000000064
113	71.97%	0.00000007197%	0.0000001760	0.0000000062
114	72.61%	0.00000007261%	0.0000001775	0.0000000061
115	73.25%	0.00000007325%	0.0000001791	0.0000000060
116	73.89%	0.00000007389%	0.0000001806	0.0000000059
117	74.52%	0.00000007452%	0.0000001822	0.0000000057
118	75.16%	0.00000007516%	0.0000001838	0.0000000056
119	75.80%	0.00000007580%	0.0000001853	0.0000000055
120	76.43%	0.00000007643%	0.0000001869	0.0000000054
121	77.07%	0.00000007707%	0.0000001884	0.0000000053
122	77.71%	0.00000007771%	0.0000001900	0.0000000052
123	78.34%	0.00000007834%	0.0000001916	0.0000000051
124	78.98%	0.00000007898%	0.0000001931	0.0000000049
125	79.62%	0.00000007962%	0.0000001947	0.0000000048
126	80.25%	0.00000008025%	0.0000001962	0.0000000047
127	80.89%	0.00000008089%	0.0000001978	0.0000000046
128	81.53%	0.00000008153%	0.0000001993	0.0000000045
129	82.17%	0.00000008217%	0.0000002009	0.0000000044
130	82.80%	0.00000008280%	0.0000002025	0.0000000043
131	83.44%	0.00000008344%	0.0000002040	0.0000000042
132	84.08%	0.00000008408%	0.0000002056	0.0000000042
133	84.71%	0.00000008471%	0.0000002071	0.0000000041
134	85.35%	0.00000008535%	0.0000002087	0.0000000040
135	85.99%	0.00000008599%	0.0000002102	0.0000000039
136	86.62%	0.00000008662%	0.0000002118	0.0000000038
137	87.26%	0.00000008726%	0.0000002134	0.0000000037

138	87.90%	0.00000008790%	0.0000002149	0.0000000036
139	88.54%	0.00000008854%	0.0000002165	0.0000000036
140	89.17%	0.00000008917%	0.0000002180	0.0000000035
141	89.81%	0.00000008981%	0.0000002196	0.0000000034
142	90.45%	0.00000009045%	0.0000002211	0.0000000033
143	91.08%	0.00000009108%	0.0000002227	0.0000000033
144	91.72%	0.00000009172%	0.0000002243	0.0000000032
145	92.36%	0.00000009236%	0.0000002258	0.0000000031
146	92.99%	0.00000009299%	0.0000002274	0.0000000030
147	93.63%	0.00000009363%	0.0000002289	0.0000000030
148	94.27%	0.00000009427%	0.0000002305	0.0000000029
149	94.90%	0.00000009490%	0.0000002320	0.0000000028
150	95.54%	0.00000009554%	0.0000002336	0.0000000028
151	96.18%	0.00000009618%	0.0000002352	0.0000000027
152	96.82%	0.00000009682%	0.0000002367	0.0000000026
153	97.45%	0.00000009745%	0.0000002383	0.0000000026
154	98.09%	0.00000009809%	0.0000002398	0.0000000025
155	98.73%	0.00000009873%	0.0000002414	0.0000000025
156	99.36%	0.00000009936%	0.0000002429	0.0000000024
157	100.00%	0.00000010000%	0.0000002445	0.0000000024
Beyond (e)				0.0000000787
Total				0.0000017651

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.00000000000%	0.0000000000	0.0000000000
18	0.57%	0.00000000057%	0.0000000016	0.0000000009
19	1.15%	0.00000000115%	0.0000000031	0.0000000018
20	1.72%	0.00000000172%	0.0000000047	0.0000000026
21	2.30%	0.00000000230%	0.0000000062	0.0000000033
22	2.87%	0.00000000287%	0.0000000078	0.0000000041
23	3.45%	0.00000000345%	0.0000000093	0.0000000047
24	4.02%	0.00000000402%	0.0000000109	0.0000000054
25	4.60%	0.00000000460%	0.0000000124	0.0000000059
26	5.17%	0.00000000517%	0.0000000140	0.0000000065
27	5.75%	0.00000000575%	0.0000000155	0.0000000070
28	6.32%	0.00000000632%	0.0000000171	0.0000000075
29	6.90%	0.00000000690%	0.0000000187	0.0000000079
30	7.47%	0.00000000747%	0.0000000202	0.0000000083
31	8.05%	0.00000000805%	0.0000000218	0.0000000087
32	8.62%	0.00000000862%	0.0000000233	0.0000000091
33	9.20%	0.00000000920%	0.0000000249	0.0000000094
34	9.77%	0.00000000977%	0.0000000264	0.0000000097
35	10.34%	0.00000001034%	0.0000000280	0.0000000099
36	10.92%	0.00000001092%	0.0000000295	0.0000000102
37	11.49%	0.00000001149%	0.0000000311	0.0000000104

38	12.07%	0.00000001207%	0.0000000326	0.0000000106
39	12.64%	0.00000001264%	0.0000000342	0.0000000108
40	13.22%	0.00000001322%	0.0000000358	0.0000000110
41	13.79%	0.00000001379%	0.0000000373	0.0000000111
42	14.37%	0.00000001437%	0.0000000389	0.0000000112
43	14.94%	0.00000001494%	0.0000000404	0.0000000113
44	15.52%	0.00000001552%	0.0000000420	0.0000000114
45	16.09%	0.00000001609%	0.0000000435	0.0000000115
46	16.67%	0.00000001667%	0.0000000451	0.0000000116
47	17.24%	0.00000001724%	0.0000000466	0.0000000116
48	17.82%	0.00000001782%	0.0000000482	0.0000000117
49	18.39%	0.00000001839%	0.0000000497	0.0000000117
50	18.97%	0.00000001897%	0.0000000513	0.0000000117
51	19.54%	0.00000001954%	0.0000000529	0.0000000117
52	20.11%	0.00000002011%	0.0000000544	0.0000000117
53	20.69%	0.00000002069%	0.0000000560	0.0000000117
54	21.26%	0.00000002126%	0.0000000575	0.0000000117
55	21.84%	0.00000002184%	0.0000000591	0.0000000116
56	22.41%	0.00000002241%	0.0000000606	0.0000000116
57	22.99%	0.00000002299%	0.0000000622	0.0000000115
58	23.56%	0.00000002356%	0.0000000637	0.0000000115
59	24.14%	0.00000002414%	0.0000000653	0.0000000114
60	24.71%	0.00000002471%	0.0000000668	0.0000000113
61	25.29%	0.00000002529%	0.0000000684	0.0000000113
62	25.86%	0.00000002586%	0.0000000700	0.0000000112
63	26.44%	0.00000002644%	0.0000000715	0.0000000111
64	27.01%	0.00000002701%	0.0000000731	0.0000000110
65	27.59%	0.00000002759%	0.0000000746	0.0000000109
66	28.16%	0.00000002816%	0.0000000762	0.0000000108
67	28.74%	0.00000002874%	0.0000000777	0.0000000107
68	29.31%	0.00000002931%	0.0000000793	0.0000000106
69	29.89%	0.00000002989%	0.0000000808	0.0000000105
70	30.46%	0.00000003046%	0.0000000824	0.0000000104
71	31.03%	0.00000003103%	0.0000000839	0.0000000103
72	31.61%	0.00000003161%	0.0000000855	0.0000000102
73	32.18%	0.00000003218%	0.0000000871	0.0000000101
74	32.76%	0.00000003276%	0.0000000886	0.0000000099
75	33.33%	0.00000003333%	0.0000000902	0.0000000098
76	33.91%	0.00000003391%	0.0000000917	0.0000000097
77	34.48%	0.00000003448%	0.0000000933	0.0000000096
78	35.06%	0.00000003506%	0.0000000948	0.0000000095
79	35.63%	0.00000003563%	0.0000000964	0.0000000093
80	36.21%	0.00000003621%	0.0000000979	0.0000000092
81	36.78%	0.00000003678%	0.0000000995	0.0000000091
82	37.36%	0.00000003736%	0.0000001010	0.0000000090
83	37.93%	0.00000003793%	0.0000001026	0.0000000088
84	38.51%	0.00000003851%	0.0000001042	0.0000000087
85	39.08%	0.00000003908%	0.0000001057	0.0000000086
86	39.66%	0.00000003966%	0.0000001073	0.0000000084
87	40.23%	0.00000004023%	0.0000001088	0.0000000083
88	40.80%	0.00000004080%	0.0000001104	0.0000000082
89	41.38%	0.00000004138%	0.0000001119	0.0000000081

90	41.95%	0.00000004195%	0.0000001135	0.0000000079
91	42.53%	0.00000004253%	0.0000001150	0.0000000078
92	43.10%	0.00000004310%	0.0000001166	0.0000000077
93	43.68%	0.00000004368%	0.0000001181	0.0000000076
94	44.25%	0.00000004425%	0.0000001197	0.0000000074
95	44.83%	0.00000004483%	0.0000001213	0.0000000073
96	45.40%	0.00000004540%	0.0000001228	0.0000000072
97	45.98%	0.00000004598%	0.0000001244	0.0000000071
98	46.55%	0.00000004655%	0.0000001259	0.0000000070
99	47.13%	0.00000004713%	0.0000001275	0.0000000068
100	47.70%	0.00000004770%	0.0000001290	0.0000000067
101	48.28%	0.00000004828%	0.0000001306	0.0000000066
102	48.85%	0.00000004885%	0.0000001321	0.0000000065
103	49.43%	0.00000004943%	0.0000001337	0.0000000064
104	50.00%	0.00000005000%	0.0000001353	0.0000000063
105	50.57%	0.00000005057%	0.0000001368	0.0000000061
106	51.15%	0.00000005115%	0.0000001384	0.0000000060
107	51.72%	0.00000005172%	0.0000001399	0.0000000059
108	52.30%	0.00000005230%	0.0000001415	0.0000000058
109	52.87%	0.00000005287%	0.0000001430	0.0000000057
110	53.45%	0.00000005345%	0.0000001446	0.0000000056
111	54.02%	0.00000005402%	0.0000001461	0.0000000055
112	54.60%	0.00000005460%	0.0000001477	0.0000000054
113	55.17%	0.00000005517%	0.0000001492	0.0000000053
114	55.75%	0.00000005575%	0.0000001508	0.0000000052
115	56.32%	0.00000005632%	0.0000001524	0.0000000051
116	56.90%	0.00000005690%	0.0000001539	0.0000000050
117	57.47%	0.00000005747%	0.0000001555	0.0000000049
118	58.05%	0.00000005805%	0.0000001570	0.0000000048
119	58.62%	0.00000005862%	0.0000001586	0.0000000047
120	59.20%	0.00000005920%	0.0000001601	0.0000000046
121	59.77%	0.00000005977%	0.0000001617	0.0000000045
122	60.34%	0.00000006034%	0.0000001632	0.0000000044
123	60.92%	0.00000006092%	0.0000001648	0.0000000043
124	61.49%	0.00000006149%	0.0000001663	0.0000000043
125	62.07%	0.00000006207%	0.0000001679	0.0000000042
126	62.64%	0.00000006264%	0.0000001695	0.0000000041
127	63.22%	0.00000006322%	0.0000001710	0.0000000040
128	63.79%	0.00000006379%	0.0000001726	0.0000000039
129	64.37%	0.00000006437%	0.0000001741	0.0000000038
130	64.94%	0.00000006494%	0.0000001757	0.0000000038
131	65.52%	0.00000006552%	0.0000001772	0.0000000037
132	66.09%	0.00000006609%	0.0000001788	0.0000000036
133	66.67%	0.00000006667%	0.0000001803	0.0000000035
134	67.24%	0.00000006724%	0.0000001819	0.0000000035
135	67.82%	0.00000006782%	0.0000001834	0.0000000034
136	68.39%	0.00000006839%	0.0000001850	0.0000000033
137	68.97%	0.00000006897%	0.0000001866	0.0000000033
138	69.54%	0.00000006954%	0.0000001881	0.0000000032
139	70.11%	0.00000007011%	0.0000001897	0.0000000031
140	70.69%	0.00000007069%	0.0000001912	0.0000000031
141	71.26%	0.00000007126%	0.0000001928	0.0000000030

142	71.84%	0.00000007184%	0.0000001943	0.0000000029
143	72.41%	0.00000007241%	0.0000001959	0.0000000029
144	72.99%	0.00000007299%	0.0000001974	0.0000000028
145	73.56%	0.00000007356%	0.0000001990	0.0000000027
146	74.14%	0.00000007414%	0.0000002005	0.0000000027
147	74.71%	0.00000007471%	0.0000002021	0.0000000026
148	75.29%	0.00000007529%	0.0000002037	0.0000000026
149	75.86%	0.00000007586%	0.0000002052	0.0000000025
150	76.44%	0.00000007644%	0.0000002068	0.0000000025
151	77.01%	0.00000007701%	0.0000002083	0.0000000024
152	77.59%	0.00000007759%	0.0000002099	0.0000000023
153	78.16%	0.00000007816%	0.0000002114	0.0000000023
154	78.74%	0.00000007874%	0.0000002130	0.0000000022
155	79.31%	0.00000007931%	0.0000002145	0.0000000022
156	79.89%	0.00000007989%	0.0000002161	0.0000000021
157	80.46%	0.00000008046%	0.0000002176	0.0000000021
158	81.03%	0.00000008103%	0.0000002192	0.0000000021
159	81.61%	0.00000008161%	0.0000002208	0.0000000020
160	82.18%	0.00000008218%	0.0000002223	0.0000000020
161	82.76%	0.00000008276%	0.0000002239	0.0000000019
162	83.33%	0.00000008333%	0.0000002254	0.0000000019
163	83.91%	0.00000008391%	0.0000002270	0.0000000018
164	84.48%	0.00000008448%	0.0000002285	0.0000000018
165	85.06%	0.00000008506%	0.0000002301	0.0000000018
166	85.63%	0.00000008563%	0.0000002316	0.0000000017
167	86.21%	0.00000008621%	0.0000002332	0.0000000017
168	86.78%	0.00000008678%	0.0000002347	0.0000000016
169	87.36%	0.00000008736%	0.0000002363	0.0000000016
170	87.93%	0.00000008793%	0.0000002379	0.0000000016
171	88.51%	0.00000008851%	0.0000002394	0.0000000015
172	89.08%	0.00000008908%	0.0000002410	0.0000000015
173	89.66%	0.00000008966%	0.0000002425	0.0000000015
174	90.23%	0.00000009023%	0.0000002441	0.0000000014
175	90.80%	0.00000009080%	0.0000002456	0.0000000014
176	91.38%	0.00000009138%	0.0000002472	0.0000000014
177	91.95%	0.00000009195%	0.0000002487	0.0000000013
178	92.53%	0.00000009253%	0.0000002503	0.0000000013
179	93.10%	0.00000009310%	0.0000002518	0.0000000013
180	93.68%	0.00000009368%	0.0000002534	0.0000000012
181	94.25%	0.00000009425%	0.0000002550	0.0000000012
182	94.83%	0.00000009483%	0.0000002565	0.0000000012
183	95.40%	0.00000009540%	0.0000002581	0.0000000012
184	95.98%	0.00000009598%	0.0000002596	0.0000000011
185	96.55%	0.00000009655%	0.0000002612	0.0000000011
186	97.13%	0.00000009713%	0.0000002627	0.0000000011
187	97.70%	0.00000009770%	0.0000002643	0.0000000011
188	98.28%	0.00000009828%	0.0000002658	0.0000000010
189	98.85%	0.00000009885%	0.0000002674	0.0000000010
190	99.43%	0.00000009943%	0.0000002689	0.0000000010
191	100.00%	0.00000010000%	0.0000002705	0.0000000010
Beyond (f)				0.0000000319
Total				0.0000010701

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.0000000000	0.0000000000
1	0.57%	0.00000000057%	0.0000000016	0.0000000015
2	1.15%	0.00000000115%	0.0000000031	0.0000000029
3	1.72%	0.00000000172%	0.0000000047	0.0000000043
4	2.30%	0.00000000230%	0.0000000062	0.0000000055
5	2.87%	0.00000000287%	0.0000000078	0.0000000067
6	3.45%	0.00000000345%	0.0000000093	0.0000000078
7	4.02%	0.00000000402%	0.0000000109	0.0000000088
8	4.60%	0.00000000460%	0.0000000124	0.0000000098
9	5.17%	0.00000000517%	0.0000000140	0.0000000107
10	5.75%	0.00000000575%	0.0000000155	0.0000000116
11	6.32%	0.00000000632%	0.0000000171	0.0000000124
12	6.90%	0.00000000690%	0.0000000187	0.0000000131
13	7.47%	0.00000000747%	0.0000000202	0.0000000138
14	8.05%	0.00000000805%	0.0000000218	0.0000000144
15	8.62%	0.00000000862%	0.0000000233	0.0000000150
16	9.20%	0.00000000920%	0.0000000249	0.0000000155
17	9.77%	0.00000000977%	0.0000000264	0.0000000160
18	10.34%	0.00000001034%	0.0000000280	0.0000000164
19	10.92%	0.00000001092%	0.0000000295	0.0000000168
20	11.49%	0.00000001149%	0.0000000311	0.0000000172
21	12.07%	0.00000001207%	0.0000000326	0.0000000175
22	12.64%	0.00000001264%	0.0000000342	0.0000000178
23	13.22%	0.00000001322%	0.0000000358	0.0000000181
24	13.79%	0.00000001379%	0.0000000373	0.0000000184
25	14.37%	0.00000001437%	0.0000000389	0.0000000186
26	14.94%	0.00000001494%	0.0000000404	0.0000000187
27	15.52%	0.00000001552%	0.0000000420	0.0000000189
28	16.09%	0.00000001609%	0.0000000435	0.0000000190
29	16.67%	0.00000001667%	0.0000000451	0.0000000191
30	17.24%	0.00000001724%	0.0000000466	0.0000000192
31	17.82%	0.00000001782%	0.0000000482	0.0000000193
32	18.39%	0.00000001839%	0.0000000497	0.0000000193
33	18.97%	0.00000001897%	0.0000000513	0.0000000193
34	19.54%	0.00000001954%	0.0000000529	0.0000000193
35	20.11%	0.00000002011%	0.0000000544	0.0000000193
36	20.69%	0.00000002069%	0.0000000560	0.0000000193
37	21.26%	0.00000002126%	0.0000000575	0.0000000193
38	21.84%	0.00000002184%	0.0000000591	0.0000000192
39	22.41%	0.00000002241%	0.0000000606	0.0000000191
40	22.99%	0.00000002299%	0.0000000622	0.0000000191
41	23.56%	0.00000002356%	0.0000000637	0.0000000190
42	24.14%	0.00000002414%	0.0000000653	0.0000000189

43	24.71%	0.00000002471%	0.0000000668	0.0000000188
44	25.29%	0.00000002529%	0.0000000684	0.0000000186
45	25.86%	0.00000002586%	0.0000000700	0.0000000185
46	26.44%	0.00000002644%	0.0000000715	0.0000000184
47	27.01%	0.00000002701%	0.0000000731	0.0000000182
48	27.59%	0.00000002759%	0.0000000746	0.0000000181
49	28.16%	0.00000002816%	0.0000000762	0.0000000179
50	28.74%	0.00000002874%	0.0000000777	0.0000000177
51	29.31%	0.00000002931%	0.0000000793	0.0000000176
52	29.89%	0.00000002989%	0.0000000808	0.0000000174
53	30.46%	0.00000003046%	0.0000000824	0.0000000172
54	31.03%	0.00000003103%	0.0000000839	0.0000000170
55	31.61%	0.00000003161%	0.0000000855	0.0000000168
56	32.18%	0.00000003218%	0.0000000871	0.0000000166
57	32.76%	0.00000003276%	0.0000000886	0.0000000164
58	33.33%	0.00000003333%	0.0000000902	0.0000000162
59	33.91%	0.00000003391%	0.0000000917	0.0000000160
60	34.48%	0.00000003448%	0.0000000933	0.0000000158
61	35.06%	0.00000003506%	0.0000000948	0.0000000156
62	35.63%	0.00000003563%	0.0000000964	0.0000000154
63	36.21%	0.00000003621%	0.0000000979	0.0000000152
64	36.78%	0.00000003678%	0.0000000995	0.0000000150
65	37.36%	0.00000003736%	0.0000001010	0.0000000148
66	37.93%	0.00000003793%	0.0000001026	0.0000000146
67	38.51%	0.00000003851%	0.0000001042	0.0000000144
68	39.08%	0.00000003908%	0.0000001057	0.0000000142
69	39.66%	0.00000003966%	0.0000001073	0.0000000140
70	40.23%	0.00000004023%	0.0000001088	0.0000000137
71	40.80%	0.00000004080%	0.0000001104	0.0000000135
72	41.38%	0.00000004138%	0.0000001119	0.0000000133
73	41.95%	0.00000004195%	0.0000001135	0.0000000131
74	42.53%	0.00000004253%	0.0000001150	0.0000000129
75	43.10%	0.00000004310%	0.0000001166	0.0000000127
76	43.68%	0.00000004368%	0.0000001181	0.0000000125
77	44.25%	0.00000004425%	0.0000001197	0.0000000123
78	44.83%	0.00000004483%	0.0000001213	0.0000000121
79	45.40%	0.00000004540%	0.0000001228	0.0000000119
80	45.98%	0.00000004598%	0.0000001244	0.0000000117
81	46.55%	0.00000004655%	0.0000001259	0.0000000115
82	47.13%	0.00000004713%	0.0000001275	0.0000000113
83	47.70%	0.00000004770%	0.0000001290	0.0000000111
84	48.28%	0.00000004828%	0.0000001306	0.0000000109
85	48.85%	0.00000004885%	0.0000001321	0.0000000107
86	49.43%	0.00000004943%	0.0000001337	0.0000000105
87	50.00%	0.00000005000%	0.0000001353	0.0000000103
88	50.57%	0.00000005057%	0.0000001368	0.0000000101
89	51.15%	0.00000005115%	0.0000001384	0.0000000100
90	51.72%	0.00000005172%	0.0000001399	0.0000000098
91	52.30%	0.00000005230%	0.0000001415	0.0000000096
92	52.87%	0.00000005287%	0.0000001430	0.0000000094
93	53.45%	0.00000005345%	0.0000001446	0.0000000093
94	54.02%	0.00000005402%	0.0000001461	0.0000000091

95	54.60%	0.00000005460%	0.0000001477	0.0000000089
96	55.17%	0.00000005517%	0.0000001492	0.0000000087
97	55.75%	0.00000005575%	0.0000001508	0.0000000086
98	56.32%	0.00000005632%	0.0000001524	0.0000000084
99	56.90%	0.00000005690%	0.0000001539	0.0000000082
100	57.47%	0.00000005747%	0.0000001555	0.0000000081
101	58.05%	0.00000005805%	0.0000001570	0.0000000079
102	58.62%	0.00000005862%	0.0000001586	0.0000000078
103	59.20%	0.00000005920%	0.0000001601	0.0000000076
104	59.77%	0.00000005977%	0.0000001617	0.0000000075
105	60.34%	0.00000006034%	0.0000001632	0.0000000073
106	60.92%	0.00000006092%	0.0000001648	0.0000000072
107	61.49%	0.00000006149%	0.0000001663	0.0000000070
108	62.07%	0.00000006207%	0.0000001679	0.0000000069
109	62.64%	0.00000006264%	0.0000001695	0.0000000068
110	63.22%	0.00000006322%	0.0000001710	0.0000000066
111	63.79%	0.00000006379%	0.0000001726	0.0000000065
112	64.37%	0.00000006437%	0.0000001741	0.0000000064
113	64.94%	0.00000006494%	0.0000001757	0.0000000062
114	65.52%	0.00000006552%	0.0000001772	0.0000000061
115	66.09%	0.00000006609%	0.0000001788	0.0000000060
116	66.67%	0.00000006667%	0.0000001803	0.0000000058
117	67.24%	0.00000006724%	0.0000001819	0.0000000057
118	67.82%	0.00000006782%	0.0000001834	0.0000000056
119	68.39%	0.00000006839%	0.0000001850	0.0000000055
120	68.97%	0.00000006897%	0.0000001866	0.0000000054
121	69.54%	0.00000006954%	0.0000001881	0.0000000053
122	70.11%	0.00000007011%	0.0000001897	0.0000000052
123	70.69%	0.00000007069%	0.0000001912	0.0000000050
124	71.26%	0.00000007126%	0.0000001928	0.0000000049
125	71.84%	0.00000007184%	0.0000001943	0.0000000048
126	72.41%	0.00000007241%	0.0000001959	0.0000000047
127	72.99%	0.00000007299%	0.0000001974	0.0000000046
128	73.56%	0.00000007356%	0.0000001990	0.0000000045
129	74.14%	0.00000007414%	0.0000002005	0.0000000044
130	74.71%	0.00000007471%	0.0000002021	0.0000000043
131	75.29%	0.00000007529%	0.0000002037	0.0000000042
132	75.86%	0.00000007586%	0.0000002052	0.0000000041
133	76.44%	0.00000007644%	0.0000002068	0.0000000041
134	77.01%	0.00000007701%	0.0000002083	0.0000000040
135	77.59%	0.00000007759%	0.0000002099	0.0000000039
136	78.16%	0.00000007816%	0.0000002114	0.0000000038
137	78.74%	0.00000007874%	0.0000002130	0.0000000037
138	79.31%	0.00000007931%	0.0000002145	0.0000000036
139	79.89%	0.00000007989%	0.0000002161	0.0000000036
140	80.46%	0.00000008046%	0.0000002176	0.0000000035
141	81.03%	0.00000008103%	0.0000002192	0.0000000034
142	81.61%	0.00000008161%	0.0000002208	0.0000000033
143	82.18%	0.00000008218%	0.0000002223	0.0000000032
144	82.76%	0.00000008276%	0.0000002239	0.0000000032
145	83.33%	0.00000008333%	0.0000002254	0.0000000031
146	83.91%	0.00000008391%	0.0000002270	0.0000000030

147	84.48%	0.00000008448%	0.0000002285	0.0000000030
148	85.06%	0.00000008506%	0.0000002301	0.0000000029
149	85.63%	0.00000008563%	0.0000002316	0.0000000028
150	86.21%	0.00000008621%	0.0000002332	0.0000000028
151	86.78%	0.00000008678%	0.0000002347	0.0000000027
152	87.36%	0.00000008736%	0.0000002363	0.0000000026
153	87.93%	0.00000008793%	0.0000002379	0.0000000026
154	88.51%	0.00000008851%	0.0000002394	0.0000000025
155	89.08%	0.00000008908%	0.0000002410	0.0000000025
156	89.66%	0.00000008966%	0.0000002425	0.0000000024
157	90.23%	0.00000009023%	0.0000002441	0.0000000024
158	90.80%	0.00000009080%	0.0000002456	0.0000000023
159	91.38%	0.00000009138%	0.0000002472	0.0000000022
160	91.95%	0.00000009195%	0.0000002487	0.0000000022
161	92.53%	0.00000009253%	0.0000002503	0.0000000021
162	93.10%	0.00000009310%	0.0000002518	0.0000000021
163	93.68%	0.00000009368%	0.0000002534	0.0000000020
164	94.25%	0.00000009425%	0.0000002550	0.0000000020
165	94.83%	0.00000009483%	0.0000002565	0.0000000020
166	95.40%	0.00000009540%	0.0000002581	0.0000000019
167	95.98%	0.00000009598%	0.0000002596	0.0000000019
168	96.55%	0.00000009655%	0.0000002612	0.0000000018
169	97.13%	0.00000009713%	0.0000002627	0.0000000018
170	97.70%	0.00000009770%	0.0000002643	0.0000000017
171	98.28%	0.00000009828%	0.0000002658	0.0000000017
172	98.85%	0.00000009885%	0.0000002674	0.0000000017
173	99.43%	0.00000009943%	0.0000002689	0.0000000016
174	100.00%	0.00000010000%	0.0000002705	0.0000000016
Beyond (g)				0.0000000526
Total				0.0000017688

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%

20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	0.00000632
Lake Ashtabula - Jump Dispersal (acres):	0.00000716
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.0000000801
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.0000000486
Lower Sheyenne River - Jump Dispersal (river-miles):	0.0000000803

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 158 into perpetuity

(f) From year 192 into perpetuity

(g) From year 175 into perpetuity

(h) From year 26 into perpetuity

Appendix 2C. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Slow Invasion - Low Risk (One Organism)

Probability of successful invasion:	1.00E-06
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.0000000	0.0000000
1	5.88%	0.00000588%	0.0003079	0.0002989
2	11.76%	0.00001176%	0.0006158	0.0005804
3	17.65%	0.00001765%	0.0009236	0.0008453
4	23.53%	0.00002353%	0.0012315	0.0010942
5	29.41%	0.00002941%	0.0015394	0.0013279
6	35.29%	0.00003529%	0.0018473	0.0015471
7	41.18%	0.00004118%	0.0021552	0.0017524
8	47.06%	0.00004706%	0.0024631	0.0019444
9	52.94%	0.00005294%	0.0027709	0.0021237
10	58.82%	0.00005882%	0.0030788	0.0022909
11	64.71%	0.00006471%	0.0033867	0.0024466
12	70.59%	0.00007059%	0.0036946	0.0025913
13	76.47%	0.00007647%	0.0040025	0.0027255
14	82.35%	0.00008235%	0.0043104	0.0028497
15	88.24%	0.00008824%	0.0046182	0.0029643
16	94.12%	0.00009412%	0.0049261	0.0030698
17	100.00%	0.00010000%	0.0052340	0.0031667
Beyond (c)				0.1055552
Total				0.1391741

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.0000000	0.0000000
1	12.50%	0.00001250%	0.0006543	0.0006352

2	25.00%	0.00002500%	0.0013085	0.0012334
3	37.50%	0.00003750%	0.0019628	0.0017962
4	50.00%	0.00005000%	0.0026170	0.0023252
5	62.50%	0.00006250%	0.0032713	0.0028218
6	75.00%	0.00007500%	0.0039255	0.0032875
7	87.50%	0.00008750%	0.0045798	0.0037238
8	100.00%	0.00010000%	0.0052340	0.0041318
Beyond (d)				0.1377256
Total				0.1576804

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.0000000	0.0000000
1	0.64%	0.00000064%	0.0000016	0.0000015
2	1.27%	0.00000127%	0.0000031	0.0000029
3	1.91%	0.00000191%	0.0000047	0.0000043
4	2.55%	0.00000255%	0.0000062	0.0000055
5	3.18%	0.00000318%	0.0000078	0.0000067
6	3.82%	0.00000382%	0.0000093	0.0000078
7	4.46%	0.00000446%	0.0000109	0.0000089
8	5.10%	0.00000510%	0.0000125	0.0000098
9	5.73%	0.00000573%	0.0000140	0.0000107
10	6.37%	0.00000637%	0.0000156	0.0000116
11	7.01%	0.00000701%	0.0000171	0.0000124
12	7.64%	0.00000764%	0.0000187	0.0000131
13	8.28%	0.00000828%	0.0000202	0.0000138
14	8.92%	0.00000892%	0.0000218	0.0000144
15	9.55%	0.00000955%	0.0000234	0.0000150
16	10.19%	0.00001019%	0.0000249	0.0000155
17	10.83%	0.00001083%	0.0000265	0.0000160
18	11.46%	0.00001146%	0.0000280	0.0000165
19	12.10%	0.00001210%	0.0000296	0.0000169
20	12.74%	0.00001274%	0.0000311	0.0000172
21	13.38%	0.00001338%	0.0000327	0.0000176
22	14.01%	0.00001401%	0.0000343	0.0000179
23	14.65%	0.00001465%	0.0000358	0.0000181
24	15.29%	0.00001529%	0.0000374	0.0000184
25	15.92%	0.00001592%	0.0000389	0.0000186
26	16.56%	0.00001656%	0.0000405	0.0000188
27	17.20%	0.00001720%	0.0000420	0.0000189
28	17.83%	0.00001783%	0.0000436	0.0000191
29	18.47%	0.00001847%	0.0000452	0.0000192
30	19.11%	0.00001911%	0.0000467	0.0000192
31	19.75%	0.00001975%	0.0000483	0.0000193
32	20.38%	0.00002038%	0.0000498	0.0000194
33	21.02%	0.00002102%	0.0000514	0.0000194

34	21.66%	0.00002166%	0.0000529	0.0000194
35	22.29%	0.00002229%	0.0000545	0.0000194
36	22.93%	0.00002293%	0.0000561	0.0000193
37	23.57%	0.00002357%	0.0000576	0.0000193
38	24.20%	0.00002420%	0.0000592	0.0000192
39	24.84%	0.00002484%	0.0000607	0.0000192
40	25.48%	0.00002548%	0.0000623	0.0000191
41	26.11%	0.00002611%	0.0000639	0.0000190
42	26.75%	0.00002675%	0.0000654	0.0000189
43	27.39%	0.00002739%	0.0000670	0.0000188
44	28.03%	0.00002803%	0.0000685	0.0000187
45	28.66%	0.00002866%	0.0000701	0.0000185
46	29.30%	0.00002930%	0.0000716	0.0000184
47	29.94%	0.00002994%	0.0000732	0.0000182
48	30.57%	0.00003057%	0.0000748	0.0000181
49	31.21%	0.00003121%	0.0000763	0.0000179
50	31.85%	0.00003185%	0.0000779	0.0000178
51	32.48%	0.00003248%	0.0000794	0.0000176
52	33.12%	0.00003312%	0.0000810	0.0000174
53	33.76%	0.00003376%	0.0000825	0.0000172
54	34.39%	0.00003439%	0.0000841	0.0000170
55	35.03%	0.00003503%	0.0000857	0.0000169
56	35.67%	0.00003567%	0.0000872	0.0000167
57	36.31%	0.00003631%	0.0000888	0.0000165
58	36.94%	0.00003694%	0.0000903	0.0000163
59	37.58%	0.00003758%	0.0000919	0.0000161
60	38.22%	0.00003822%	0.0000934	0.0000159
61	38.85%	0.00003885%	0.0000950	0.0000157
62	39.49%	0.00003949%	0.0000966	0.0000154
63	40.13%	0.00004013%	0.0000981	0.0000152
64	40.76%	0.00004076%	0.0000997	0.0000150
65	41.40%	0.00004140%	0.0001012	0.0000148
66	42.04%	0.00004204%	0.0001028	0.0000146
67	42.68%	0.00004268%	0.0001043	0.0000144
68	43.31%	0.00004331%	0.0001059	0.0000142
69	43.95%	0.00004395%	0.0001075	0.0000140
70	44.59%	0.00004459%	0.0001090	0.0000138
71	45.22%	0.00004522%	0.0001106	0.0000136
72	45.86%	0.00004586%	0.0001121	0.0000133
73	46.50%	0.00004650%	0.0001137	0.0000131
74	47.13%	0.00004713%	0.0001152	0.0000129
75	47.77%	0.00004777%	0.0001168	0.0000127
76	48.41%	0.00004841%	0.0001184	0.0000125
77	49.04%	0.00004904%	0.0001199	0.0000123
78	49.68%	0.00004968%	0.0001215	0.0000121
79	50.32%	0.00005032%	0.0001230	0.0000119
80	50.96%	0.00005096%	0.0001246	0.0000117
81	51.59%	0.00005159%	0.0001261	0.0000115
82	52.23%	0.00005223%	0.0001277	0.0000113
83	52.87%	0.00005287%	0.0001293	0.0000111
84	53.50%	0.00005350%	0.0001308	0.0000109
85	54.14%	0.00005414%	0.0001324	0.0000107

86	54.78%	0.00005478%	0.0001339	0.0000105
87	55.41%	0.00005541%	0.0001355	0.0000104
88	56.05%	0.00005605%	0.0001370	0.0000102
89	56.69%	0.00005669%	0.0001386	0.0000100
90	57.32%	0.00005732%	0.0001402	0.0000098
91	57.96%	0.00005796%	0.0001417	0.0000096
92	58.60%	0.00005860%	0.0001433	0.0000094
93	59.24%	0.00005924%	0.0001448	0.0000093
94	59.87%	0.00005987%	0.0001464	0.0000091
95	60.51%	0.00006051%	0.0001479	0.0000089
96	61.15%	0.00006115%	0.0001495	0.0000088
97	61.78%	0.00006178%	0.0001511	0.0000086
98	62.42%	0.00006242%	0.0001526	0.0000084
99	63.06%	0.00006306%	0.0001542	0.0000083
100	63.69%	0.00006369%	0.0001557	0.0000081
101	64.33%	0.00006433%	0.0001573	0.0000079
102	64.97%	0.00006497%	0.0001588	0.0000078
103	65.61%	0.00006561%	0.0001604	0.0000076
104	66.24%	0.00006624%	0.0001620	0.0000075
105	66.88%	0.00006688%	0.0001635	0.0000073
106	67.52%	0.00006752%	0.0001651	0.0000072
107	68.15%	0.00006815%	0.0001666	0.0000070
108	68.79%	0.00006879%	0.0001682	0.0000069
109	69.43%	0.00006943%	0.0001697	0.0000068
110	70.06%	0.00007006%	0.0001713	0.0000066
111	70.70%	0.00007070%	0.0001729	0.0000065
112	71.34%	0.00007134%	0.0001744	0.0000064
113	71.97%	0.00007197%	0.0001760	0.0000062
114	72.61%	0.00007261%	0.0001775	0.0000061
115	73.25%	0.00007325%	0.0001791	0.0000060
116	73.89%	0.00007389%	0.0001806	0.0000059
117	74.52%	0.00007452%	0.0001822	0.0000057
118	75.16%	0.00007516%	0.0001838	0.0000056
119	75.80%	0.00007580%	0.0001853	0.0000055
120	76.43%	0.00007643%	0.0001869	0.0000054
121	77.07%	0.00007707%	0.0001884	0.0000053
122	77.71%	0.00007771%	0.0001900	0.0000052
123	78.34%	0.00007834%	0.0001916	0.0000051
124	78.98%	0.00007898%	0.0001931	0.0000049
125	79.62%	0.00007962%	0.0001947	0.0000048
126	80.25%	0.00008025%	0.0001962	0.0000047
127	80.89%	0.00008089%	0.0001978	0.0000046
128	81.53%	0.00008153%	0.0001993	0.0000045
129	82.17%	0.00008217%	0.0002009	0.0000044
130	82.80%	0.00008280%	0.0002025	0.0000043
131	83.44%	0.00008344%	0.0002040	0.0000042
132	84.08%	0.00008408%	0.0002056	0.0000042
133	84.71%	0.00008471%	0.0002071	0.0000041
134	85.35%	0.00008535%	0.0002087	0.0000040
135	85.99%	0.00008599%	0.0002102	0.0000039
136	86.62%	0.00008662%	0.0002118	0.0000038
137	87.26%	0.00008726%	0.0002134	0.0000037

138	87.90%	0.00008790%	0.0002149	0.0000036
139	88.54%	0.00008854%	0.0002165	0.0000036
140	89.17%	0.00008917%	0.0002180	0.0000035
141	89.81%	0.00008981%	0.0002196	0.0000034
142	90.45%	0.00009045%	0.0002211	0.0000033
143	91.08%	0.00009108%	0.0002227	0.0000033
144	91.72%	0.00009172%	0.0002243	0.0000032
145	92.36%	0.00009236%	0.0002258	0.0000031
146	92.99%	0.00009299%	0.0002274	0.0000030
147	93.63%	0.00009363%	0.0002289	0.0000030
148	94.27%	0.00009427%	0.0002305	0.0000029
149	94.90%	0.00009490%	0.0002320	0.0000028
150	95.54%	0.00009554%	0.0002336	0.0000028
151	96.18%	0.00009618%	0.0002352	0.0000027
152	96.82%	0.00009682%	0.0002367	0.0000026
153	97.45%	0.00009745%	0.0002383	0.0000026
154	98.09%	0.00009809%	0.0002398	0.0000025
155	98.73%	0.00009873%	0.0002414	0.0000025
156	99.36%	0.00009936%	0.0002429	0.0000024
157	100.00%	0.00010000%	0.0002445	0.0000024
Beyond (e)				0.0000787
Total				0.0017651

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.00000000%	0.0000000	0.0000000
18	0.57%	0.00000057%	0.0000016	0.0000009
19	1.15%	0.00000115%	0.0000031	0.0000018
20	1.72%	0.00000172%	0.0000047	0.0000026
21	2.30%	0.00000230%	0.0000062	0.0000033
22	2.87%	0.00000287%	0.0000078	0.0000041
23	3.45%	0.00000345%	0.0000093	0.0000047
24	4.02%	0.00000402%	0.0000109	0.0000054
25	4.60%	0.00000460%	0.0000124	0.0000059
26	5.17%	0.00000517%	0.0000140	0.0000065
27	5.75%	0.00000575%	0.0000155	0.0000070
28	6.32%	0.00000632%	0.0000171	0.0000075
29	6.90%	0.00000690%	0.0000187	0.0000079
30	7.47%	0.00000747%	0.0000202	0.0000083
31	8.05%	0.00000805%	0.0000218	0.0000087
32	8.62%	0.00000862%	0.0000233	0.0000091
33	9.20%	0.00000920%	0.0000249	0.0000094
34	9.77%	0.00000977%	0.0000264	0.0000097
35	10.34%	0.00001034%	0.0000280	0.0000099
36	10.92%	0.00001092%	0.0000295	0.0000102
37	11.49%	0.00001149%	0.0000311	0.0000104

38	12.07%	0.00001207%	0.0000326	0.0000106
39	12.64%	0.00001264%	0.0000342	0.0000108
40	13.22%	0.00001322%	0.0000358	0.0000110
41	13.79%	0.00001379%	0.0000373	0.0000111
42	14.37%	0.00001437%	0.0000389	0.0000112
43	14.94%	0.00001494%	0.0000404	0.0000113
44	15.52%	0.00001552%	0.0000420	0.0000114
45	16.09%	0.00001609%	0.0000435	0.0000115
46	16.67%	0.00001667%	0.0000451	0.0000116
47	17.24%	0.00001724%	0.0000466	0.0000116
48	17.82%	0.00001782%	0.0000482	0.0000117
49	18.39%	0.00001839%	0.0000497	0.0000117
50	18.97%	0.00001897%	0.0000513	0.0000117
51	19.54%	0.00001954%	0.0000529	0.0000117
52	20.11%	0.00002011%	0.0000544	0.0000117
53	20.69%	0.00002069%	0.0000560	0.0000117
54	21.26%	0.00002126%	0.0000575	0.0000117
55	21.84%	0.00002184%	0.0000591	0.0000116
56	22.41%	0.00002241%	0.0000606	0.0000116
57	22.99%	0.00002299%	0.0000622	0.0000115
58	23.56%	0.00002356%	0.0000637	0.0000115
59	24.14%	0.00002414%	0.0000653	0.0000114
60	24.71%	0.00002471%	0.0000668	0.0000113
61	25.29%	0.00002529%	0.0000684	0.0000113
62	25.86%	0.00002586%	0.0000700	0.0000112
63	26.44%	0.00002644%	0.0000715	0.0000111
64	27.01%	0.00002701%	0.0000731	0.0000110
65	27.59%	0.00002759%	0.0000746	0.0000109
66	28.16%	0.00002816%	0.0000762	0.0000108
67	28.74%	0.00002874%	0.0000777	0.0000107
68	29.31%	0.00002931%	0.0000793	0.0000106
69	29.89%	0.00002989%	0.0000808	0.0000105
70	30.46%	0.00003046%	0.0000824	0.0000104
71	31.03%	0.00003103%	0.0000839	0.0000103
72	31.61%	0.00003161%	0.0000855	0.0000102
73	32.18%	0.00003218%	0.0000871	0.0000101
74	32.76%	0.00003276%	0.0000886	0.0000099
75	33.33%	0.00003333%	0.0000902	0.0000098
76	33.91%	0.00003391%	0.0000917	0.0000097
77	34.48%	0.00003448%	0.0000933	0.0000096
78	35.06%	0.00003506%	0.0000948	0.0000095
79	35.63%	0.00003563%	0.0000964	0.0000093
80	36.21%	0.00003621%	0.0000979	0.0000092
81	36.78%	0.00003678%	0.0000995	0.0000091
82	37.36%	0.00003736%	0.0001010	0.0000090
83	37.93%	0.00003793%	0.0001026	0.0000088
84	38.51%	0.00003851%	0.0001042	0.0000087
85	39.08%	0.00003908%	0.0001057	0.0000086
86	39.66%	0.00003966%	0.0001073	0.0000084
87	40.23%	0.00004023%	0.0001088	0.0000083
88	40.80%	0.00004080%	0.0001104	0.0000082
89	41.38%	0.00004138%	0.0001119	0.0000081

90	41.95%	0.00004195%	0.0001135	0.0000079
91	42.53%	0.00004253%	0.0001150	0.0000078
92	43.10%	0.00004310%	0.0001166	0.0000077
93	43.68%	0.00004368%	0.0001181	0.0000076
94	44.25%	0.00004425%	0.0001197	0.0000074
95	44.83%	0.00004483%	0.0001213	0.0000073
96	45.40%	0.00004540%	0.0001228	0.0000072
97	45.98%	0.00004598%	0.0001244	0.0000071
98	46.55%	0.00004655%	0.0001259	0.0000070
99	47.13%	0.00004713%	0.0001275	0.0000068
100	47.70%	0.00004770%	0.0001290	0.0000067
101	48.28%	0.00004828%	0.0001306	0.0000066
102	48.85%	0.00004885%	0.0001321	0.0000065
103	49.43%	0.00004943%	0.0001337	0.0000064
104	50.00%	0.00005000%	0.0001353	0.0000063
105	50.57%	0.00005057%	0.0001368	0.0000061
106	51.15%	0.00005115%	0.0001384	0.0000060
107	51.72%	0.00005172%	0.0001399	0.0000059
108	52.30%	0.00005230%	0.0001415	0.0000058
109	52.87%	0.00005287%	0.0001430	0.0000057
110	53.45%	0.00005345%	0.0001446	0.0000056
111	54.02%	0.00005402%	0.0001461	0.0000055
112	54.60%	0.00005460%	0.0001477	0.0000054
113	55.17%	0.00005517%	0.0001492	0.0000053
114	55.75%	0.00005575%	0.0001508	0.0000052
115	56.32%	0.00005632%	0.0001524	0.0000051
116	56.90%	0.00005690%	0.0001539	0.0000050
117	57.47%	0.00005747%	0.0001555	0.0000049
118	58.05%	0.00005805%	0.0001570	0.0000048
119	58.62%	0.00005862%	0.0001586	0.0000047
120	59.20%	0.00005920%	0.0001601	0.0000046
121	59.77%	0.00005977%	0.0001617	0.0000045
122	60.34%	0.00006034%	0.0001632	0.0000044
123	60.92%	0.00006092%	0.0001648	0.0000043
124	61.49%	0.00006149%	0.0001663	0.0000043
125	62.07%	0.00006207%	0.0001679	0.0000042
126	62.64%	0.00006264%	0.0001695	0.0000041
127	63.22%	0.00006322%	0.0001710	0.0000040
128	63.79%	0.00006379%	0.0001726	0.0000039
129	64.37%	0.00006437%	0.0001741	0.0000038
130	64.94%	0.00006494%	0.0001757	0.0000038
131	65.52%	0.00006552%	0.0001772	0.0000037
132	66.09%	0.00006609%	0.0001788	0.0000036
133	66.67%	0.00006667%	0.0001803	0.0000035
134	67.24%	0.00006724%	0.0001819	0.0000035
135	67.82%	0.00006782%	0.0001834	0.0000034
136	68.39%	0.00006839%	0.0001850	0.0000033
137	68.97%	0.00006897%	0.0001866	0.0000033
138	69.54%	0.00006954%	0.0001881	0.0000032
139	70.11%	0.00007011%	0.0001897	0.0000031
140	70.69%	0.00007069%	0.0001912	0.0000031
141	71.26%	0.00007126%	0.0001928	0.0000030

142	71.84%	0.00007184%	0.0001943	0.0000029
143	72.41%	0.00007241%	0.0001959	0.0000029
144	72.99%	0.00007299%	0.0001974	0.0000028
145	73.56%	0.00007356%	0.0001990	0.0000027
146	74.14%	0.00007414%	0.0002005	0.0000027
147	74.71%	0.00007471%	0.0002021	0.0000026
148	75.29%	0.00007529%	0.0002037	0.0000026
149	75.86%	0.00007586%	0.0002052	0.0000025
150	76.44%	0.00007644%	0.0002068	0.0000025
151	77.01%	0.00007701%	0.0002083	0.0000024
152	77.59%	0.00007759%	0.0002099	0.0000023
153	78.16%	0.00007816%	0.0002114	0.0000023
154	78.74%	0.00007874%	0.0002130	0.0000022
155	79.31%	0.00007931%	0.0002145	0.0000022
156	79.89%	0.00007989%	0.0002161	0.0000021
157	80.46%	0.00008046%	0.0002176	0.0000021
158	81.03%	0.00008103%	0.0002192	0.0000021
159	81.61%	0.00008161%	0.0002208	0.0000020
160	82.18%	0.00008218%	0.0002223	0.0000020
161	82.76%	0.00008276%	0.0002239	0.0000019
162	83.33%	0.00008333%	0.0002254	0.0000019
163	83.91%	0.00008391%	0.0002270	0.0000018
164	84.48%	0.00008448%	0.0002285	0.0000018
165	85.06%	0.00008506%	0.0002301	0.0000018
166	85.63%	0.00008563%	0.0002316	0.0000017
167	86.21%	0.00008621%	0.0002332	0.0000017
168	86.78%	0.00008678%	0.0002347	0.0000016
169	87.36%	0.00008736%	0.0002363	0.0000016
170	87.93%	0.00008793%	0.0002379	0.0000016
171	88.51%	0.00008851%	0.0002394	0.0000015
172	89.08%	0.00008908%	0.0002410	0.0000015
173	89.66%	0.00008966%	0.0002425	0.0000015
174	90.23%	0.00009023%	0.0002441	0.0000014
175	90.80%	0.00009080%	0.0002456	0.0000014
176	91.38%	0.00009138%	0.0002472	0.0000014
177	91.95%	0.00009195%	0.0002487	0.0000013
178	92.53%	0.00009253%	0.0002503	0.0000013
179	93.10%	0.00009310%	0.0002518	0.0000013
180	93.68%	0.00009368%	0.0002534	0.0000012
181	94.25%	0.00009425%	0.0002550	0.0000012
182	94.83%	0.00009483%	0.0002565	0.0000012
183	95.40%	0.00009540%	0.0002581	0.0000012
184	95.98%	0.00009598%	0.0002596	0.0000011
185	96.55%	0.00009655%	0.0002612	0.0000011
186	97.13%	0.00009713%	0.0002627	0.0000011
187	97.70%	0.00009770%	0.0002643	0.0000011
188	98.28%	0.00009828%	0.0002658	0.0000010
189	98.85%	0.00009885%	0.0002674	0.0000010
190	99.43%	0.00009943%	0.0002689	0.0000010
191	100.00%	0.00010000%	0.0002705	0.0000010
Beyond (f)				0.0000319
Total				0.0010701

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.0000000	0.0000000
1	0.57%	0.00000057%	0.0000016	0.0000015
2	1.15%	0.00000115%	0.0000031	0.0000029
3	1.72%	0.00000172%	0.0000047	0.0000043
4	2.30%	0.00000230%	0.0000062	0.0000055
5	2.87%	0.00000287%	0.0000078	0.0000067
6	3.45%	0.00000345%	0.0000093	0.0000078
7	4.02%	0.00000402%	0.0000109	0.0000088
8	4.60%	0.00000460%	0.0000124	0.0000098
9	5.17%	0.00000517%	0.0000140	0.0000107
10	5.75%	0.00000575%	0.0000155	0.0000116
11	6.32%	0.00000632%	0.0000171	0.0000124
12	6.90%	0.00000690%	0.0000187	0.0000131
13	7.47%	0.00000747%	0.0000202	0.0000138
14	8.05%	0.00000805%	0.0000218	0.0000144
15	8.62%	0.00000862%	0.0000233	0.0000150
16	9.20%	0.00000920%	0.0000249	0.0000155
17	9.77%	0.00000977%	0.0000264	0.0000160
18	10.34%	0.00001034%	0.0000280	0.0000164
19	10.92%	0.00001092%	0.0000295	0.0000168
20	11.49%	0.00001149%	0.0000311	0.0000172
21	12.07%	0.00001207%	0.0000326	0.0000175
22	12.64%	0.00001264%	0.0000342	0.0000178
23	13.22%	0.00001322%	0.0000358	0.0000181
24	13.79%	0.00001379%	0.0000373	0.0000184
25	14.37%	0.00001437%	0.0000389	0.0000186
26	14.94%	0.00001494%	0.0000404	0.0000187
27	15.52%	0.00001552%	0.0000420	0.0000189
28	16.09%	0.00001609%	0.0000435	0.0000190
29	16.67%	0.00001667%	0.0000451	0.0000191
30	17.24%	0.00001724%	0.0000466	0.0000192
31	17.82%	0.00001782%	0.0000482	0.0000193
32	18.39%	0.00001839%	0.0000497	0.0000193
33	18.97%	0.00001897%	0.0000513	0.0000193
34	19.54%	0.00001954%	0.0000529	0.0000193
35	20.11%	0.00002011%	0.0000544	0.0000193
36	20.69%	0.00002069%	0.0000560	0.0000193
37	21.26%	0.00002126%	0.0000575	0.0000193
38	21.84%	0.00002184%	0.0000591	0.0000192
39	22.41%	0.00002241%	0.0000606	0.0000191
40	22.99%	0.00002299%	0.0000622	0.0000191
41	23.56%	0.00002356%	0.0000637	0.0000190
42	24.14%	0.00002414%	0.0000653	0.0000189

43	24.71%	0.00002471%	0.0000668	0.0000188
44	25.29%	0.00002529%	0.0000684	0.0000186
45	25.86%	0.00002586%	0.0000700	0.0000185
46	26.44%	0.00002644%	0.0000715	0.0000184
47	27.01%	0.00002701%	0.0000731	0.0000182
48	27.59%	0.00002759%	0.0000746	0.0000181
49	28.16%	0.00002816%	0.0000762	0.0000179
50	28.74%	0.00002874%	0.0000777	0.0000177
51	29.31%	0.00002931%	0.0000793	0.0000176
52	29.89%	0.00002989%	0.0000808	0.0000174
53	30.46%	0.00003046%	0.0000824	0.0000172
54	31.03%	0.00003103%	0.0000839	0.0000170
55	31.61%	0.00003161%	0.0000855	0.0000168
56	32.18%	0.00003218%	0.0000871	0.0000166
57	32.76%	0.00003276%	0.0000886	0.0000164
58	33.33%	0.00003333%	0.0000902	0.0000162
59	33.91%	0.00003391%	0.0000917	0.0000160
60	34.48%	0.00003448%	0.0000933	0.0000158
61	35.06%	0.00003506%	0.0000948	0.0000156
62	35.63%	0.00003563%	0.0000964	0.0000154
63	36.21%	0.00003621%	0.0000979	0.0000152
64	36.78%	0.00003678%	0.0000995	0.0000150
65	37.36%	0.00003736%	0.0001010	0.0000148
66	37.93%	0.00003793%	0.0001026	0.0000146
67	38.51%	0.00003851%	0.0001042	0.0000144
68	39.08%	0.00003908%	0.0001057	0.0000142
69	39.66%	0.00003966%	0.0001073	0.0000140
70	40.23%	0.00004023%	0.0001088	0.0000137
71	40.80%	0.00004080%	0.0001104	0.0000135
72	41.38%	0.00004138%	0.0001119	0.0000133
73	41.95%	0.00004195%	0.0001135	0.0000131
74	42.53%	0.00004253%	0.0001150	0.0000129
75	43.10%	0.00004310%	0.0001166	0.0000127
76	43.68%	0.00004368%	0.0001181	0.0000125
77	44.25%	0.00004425%	0.0001197	0.0000123
78	44.83%	0.00004483%	0.0001213	0.0000121
79	45.40%	0.00004540%	0.0001228	0.0000119
80	45.98%	0.00004598%	0.0001244	0.0000117
81	46.55%	0.00004655%	0.0001259	0.0000115
82	47.13%	0.00004713%	0.0001275	0.0000113
83	47.70%	0.00004770%	0.0001290	0.0000111
84	48.28%	0.00004828%	0.0001306	0.0000109
85	48.85%	0.00004885%	0.0001321	0.0000107
86	49.43%	0.00004943%	0.0001337	0.0000105
87	50.00%	0.00005000%	0.0001353	0.0000103
88	50.57%	0.00005057%	0.0001368	0.0000101
89	51.15%	0.00005115%	0.0001384	0.0000100
90	51.72%	0.00005172%	0.0001399	0.0000098
91	52.30%	0.00005230%	0.0001415	0.0000096
92	52.87%	0.00005287%	0.0001430	0.0000094
93	53.45%	0.00005345%	0.0001446	0.0000093
94	54.02%	0.00005402%	0.0001461	0.0000091

95	54.60%	0.00005460%	0.0001477	0.0000089
96	55.17%	0.00005517%	0.0001492	0.0000087
97	55.75%	0.00005575%	0.0001508	0.0000086
98	56.32%	0.00005632%	0.0001524	0.0000084
99	56.90%	0.00005690%	0.0001539	0.0000082
100	57.47%	0.00005747%	0.0001555	0.0000081
101	58.05%	0.00005805%	0.0001570	0.0000079
102	58.62%	0.00005862%	0.0001586	0.0000078
103	59.20%	0.00005920%	0.0001601	0.0000076
104	59.77%	0.00005977%	0.0001617	0.0000075
105	60.34%	0.00006034%	0.0001632	0.0000073
106	60.92%	0.00006092%	0.0001648	0.0000072
107	61.49%	0.00006149%	0.0001663	0.0000070
108	62.07%	0.00006207%	0.0001679	0.0000069
109	62.64%	0.00006264%	0.0001695	0.0000068
110	63.22%	0.00006322%	0.0001710	0.0000066
111	63.79%	0.00006379%	0.0001726	0.0000065
112	64.37%	0.00006437%	0.0001741	0.0000064
113	64.94%	0.00006494%	0.0001757	0.0000062
114	65.52%	0.00006552%	0.0001772	0.0000061
115	66.09%	0.00006609%	0.0001788	0.0000060
116	66.67%	0.00006667%	0.0001803	0.0000058
117	67.24%	0.00006724%	0.0001819	0.0000057
118	67.82%	0.00006782%	0.0001834	0.0000056
119	68.39%	0.00006839%	0.0001850	0.0000055
120	68.97%	0.00006897%	0.0001866	0.0000054
121	69.54%	0.00006954%	0.0001881	0.0000053
122	70.11%	0.00007011%	0.0001897	0.0000052
123	70.69%	0.00007069%	0.0001912	0.0000050
124	71.26%	0.00007126%	0.0001928	0.0000049
125	71.84%	0.00007184%	0.0001943	0.0000048
126	72.41%	0.00007241%	0.0001959	0.0000047
127	72.99%	0.00007299%	0.0001974	0.0000046
128	73.56%	0.00007356%	0.0001990	0.0000045
129	74.14%	0.00007414%	0.0002005	0.0000044
130	74.71%	0.00007471%	0.0002021	0.0000043
131	75.29%	0.00007529%	0.0002037	0.0000042
132	75.86%	0.00007586%	0.0002052	0.0000041
133	76.44%	0.00007644%	0.0002068	0.0000041
134	77.01%	0.00007701%	0.0002083	0.0000040
135	77.59%	0.00007759%	0.0002099	0.0000039
136	78.16%	0.00007816%	0.0002114	0.0000038
137	78.74%	0.00007874%	0.0002130	0.0000037
138	79.31%	0.00007931%	0.0002145	0.0000036
139	79.89%	0.00007989%	0.0002161	0.0000036
140	80.46%	0.00008046%	0.0002176	0.0000035
141	81.03%	0.00008103%	0.0002192	0.0000034
142	81.61%	0.00008161%	0.0002208	0.0000033
143	82.18%	0.00008218%	0.0002223	0.0000032
144	82.76%	0.00008276%	0.0002239	0.0000032
145	83.33%	0.00008333%	0.0002254	0.0000031
146	83.91%	0.00008391%	0.0002270	0.0000030

147	84.48%	0.00008448%	0.0002285	0.0000030
148	85.06%	0.00008506%	0.0002301	0.0000029
149	85.63%	0.00008563%	0.0002316	0.0000028
150	86.21%	0.00008621%	0.0002332	0.0000028
151	86.78%	0.00008678%	0.0002347	0.0000027
152	87.36%	0.00008736%	0.0002363	0.0000026
153	87.93%	0.00008793%	0.0002379	0.0000026
154	88.51%	0.00008851%	0.0002394	0.0000025
155	89.08%	0.00008908%	0.0002410	0.0000025
156	89.66%	0.00008966%	0.0002425	0.0000024
157	90.23%	0.00009023%	0.0002441	0.0000024
158	90.80%	0.00009080%	0.0002456	0.0000023
159	91.38%	0.00009138%	0.0002472	0.0000022
160	91.95%	0.00009195%	0.0002487	0.0000022
161	92.53%	0.00009253%	0.0002503	0.0000021
162	93.10%	0.00009310%	0.0002518	0.0000021
163	93.68%	0.00009368%	0.0002534	0.0000020
164	94.25%	0.00009425%	0.0002550	0.0000020
165	94.83%	0.00009483%	0.0002565	0.0000020
166	95.40%	0.00009540%	0.0002581	0.0000019
167	95.98%	0.00009598%	0.0002596	0.0000019
168	96.55%	0.00009655%	0.0002612	0.0000018
169	97.13%	0.00009713%	0.0002627	0.0000018
170	97.70%	0.00009770%	0.0002643	0.0000017
171	98.28%	0.00009828%	0.0002658	0.0000017
172	98.85%	0.00009885%	0.0002674	0.0000017
173	99.43%	0.00009943%	0.0002689	0.0000016
174	100.00%	0.00010000%	0.0002705	0.0000016
Beyond (g)				0.0000526
Total				0.0017688

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%

20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	0.00632
Lake Ashtabula - Jump Dispersal (acres):	0.00716
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.0000801
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.0000486
Lower Sheyenne River - Jump Dispersal (river-miles):	0.0000803

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 158 into perpetuity

(f) From year 192 into perpetuity

(g) From year 175 into perpetuity

(h) From year 26 into perpetuity

Appendix 2D. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Slow Invasion - Moderate Risk (One Organism)

Probability of successful invasion:	1.00E-03
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.0000	0.0000
1	5.88%	0.00588%	0.3079	0.2989
2	11.76%	0.01176%	0.6158	0.5804
3	17.65%	0.01765%	0.9236	0.8453
4	23.53%	0.02353%	1.2315	1.0942
5	29.41%	0.02941%	1.5394	1.3279
6	35.29%	0.03529%	1.8473	1.5471
7	41.18%	0.04118%	2.1552	1.7524
8	47.06%	0.04706%	2.4631	1.9444
9	52.94%	0.05294%	2.7709	2.1237
10	58.82%	0.05882%	3.0788	2.2909
11	64.71%	0.06471%	3.3867	2.4466
12	70.59%	0.07059%	3.6946	2.5913
13	76.47%	0.07647%	4.0025	2.7255
14	82.35%	0.08235%	4.3104	2.8497
15	88.24%	0.08824%	4.6182	2.9643
16	94.12%	0.09412%	4.9261	3.0698
17	100.00%	0.10000%	5.2340	3.1667
Beyond (c)				105.5552
Total				139.1741

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.0000	0.0000
1	12.50%	0.01250%	0.6543	0.6352

2	25.00%	0.02500%	1.3085	1.2334
3	37.50%	0.03750%	1.9628	1.7962
4	50.00%	0.05000%	2.6170	2.3252
5	62.50%	0.06250%	3.2713	2.8218
6	75.00%	0.07500%	3.9255	3.2875
7	87.50%	0.08750%	4.5798	3.7238
8	100.00%	0.10000%	5.2340	4.1318
Beyond (d)				137.7256
Total				157.6804

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.0000	0.0000
1	0.64%	0.00064%	0.0016	0.0015
2	1.27%	0.00127%	0.0031	0.0029
3	1.91%	0.00191%	0.0047	0.0043
4	2.55%	0.00255%	0.0062	0.0055
5	3.18%	0.00318%	0.0078	0.0067
6	3.82%	0.00382%	0.0093	0.0078
7	4.46%	0.00446%	0.0109	0.0089
8	5.10%	0.00510%	0.0125	0.0098
9	5.73%	0.00573%	0.0140	0.0107
10	6.37%	0.00637%	0.0156	0.0116
11	7.01%	0.00701%	0.0171	0.0124
12	7.64%	0.00764%	0.0187	0.0131
13	8.28%	0.00828%	0.0202	0.0138
14	8.92%	0.00892%	0.0218	0.0144
15	9.55%	0.00955%	0.0234	0.0150
16	10.19%	0.01019%	0.0249	0.0155
17	10.83%	0.01083%	0.0265	0.0160
18	11.46%	0.01146%	0.0280	0.0165
19	12.10%	0.01210%	0.0296	0.0169
20	12.74%	0.01274%	0.0311	0.0172
21	13.38%	0.01338%	0.0327	0.0176
22	14.01%	0.01401%	0.0343	0.0179
23	14.65%	0.01465%	0.0358	0.0181
24	15.29%	0.01529%	0.0374	0.0184
25	15.92%	0.01592%	0.0389	0.0186
26	16.56%	0.01656%	0.0405	0.0188
27	17.20%	0.01720%	0.0420	0.0189
28	17.83%	0.01783%	0.0436	0.0191
29	18.47%	0.01847%	0.0452	0.0192
30	19.11%	0.01911%	0.0467	0.0192
31	19.75%	0.01975%	0.0483	0.0193
32	20.38%	0.02038%	0.0498	0.0194
33	21.02%	0.02102%	0.0514	0.0194

34	21.66%	0.02166%	0.0529	0.0194
35	22.29%	0.02229%	0.0545	0.0194
36	22.93%	0.02293%	0.0561	0.0193
37	23.57%	0.02357%	0.0576	0.0193
38	24.20%	0.02420%	0.0592	0.0192
39	24.84%	0.02484%	0.0607	0.0192
40	25.48%	0.02548%	0.0623	0.0191
41	26.11%	0.02611%	0.0639	0.0190
42	26.75%	0.02675%	0.0654	0.0189
43	27.39%	0.02739%	0.0670	0.0188
44	28.03%	0.02803%	0.0685	0.0187
45	28.66%	0.02866%	0.0701	0.0185
46	29.30%	0.02930%	0.0716	0.0184
47	29.94%	0.02994%	0.0732	0.0182
48	30.57%	0.03057%	0.0748	0.0181
49	31.21%	0.03121%	0.0763	0.0179
50	31.85%	0.03185%	0.0779	0.0178
51	32.48%	0.03248%	0.0794	0.0176
52	33.12%	0.03312%	0.0810	0.0174
53	33.76%	0.03376%	0.0825	0.0172
54	34.39%	0.03439%	0.0841	0.0170
55	35.03%	0.03503%	0.0857	0.0169
56	35.67%	0.03567%	0.0872	0.0167
57	36.31%	0.03631%	0.0888	0.0165
58	36.94%	0.03694%	0.0903	0.0163
59	37.58%	0.03758%	0.0919	0.0161
60	38.22%	0.03822%	0.0934	0.0159
61	38.85%	0.03885%	0.0950	0.0157
62	39.49%	0.03949%	0.0966	0.0154
63	40.13%	0.04013%	0.0981	0.0152
64	40.76%	0.04076%	0.0997	0.0150
65	41.40%	0.04140%	0.1012	0.0148
66	42.04%	0.04204%	0.1028	0.0146
67	42.68%	0.04268%	0.1043	0.0144
68	43.31%	0.04331%	0.1059	0.0142
69	43.95%	0.04395%	0.1075	0.0140
70	44.59%	0.04459%	0.1090	0.0138
71	45.22%	0.04522%	0.1106	0.0136
72	45.86%	0.04586%	0.1121	0.0133
73	46.50%	0.04650%	0.1137	0.0131
74	47.13%	0.04713%	0.1152	0.0129
75	47.77%	0.04777%	0.1168	0.0127
76	48.41%	0.04841%	0.1184	0.0125
77	49.04%	0.04904%	0.1199	0.0123
78	49.68%	0.04968%	0.1215	0.0121
79	50.32%	0.05032%	0.1230	0.0119
80	50.96%	0.05096%	0.1246	0.0117
81	51.59%	0.05159%	0.1261	0.0115
82	52.23%	0.05223%	0.1277	0.0113
83	52.87%	0.05287%	0.1293	0.0111
84	53.50%	0.05350%	0.1308	0.0109
85	54.14%	0.05414%	0.1324	0.0107

86	54.78%	0.05478%	0.1339	0.0105
87	55.41%	0.05541%	0.1355	0.0104
88	56.05%	0.05605%	0.1370	0.0102
89	56.69%	0.05669%	0.1386	0.0100
90	57.32%	0.05732%	0.1402	0.0098
91	57.96%	0.05796%	0.1417	0.0096
92	58.60%	0.05860%	0.1433	0.0094
93	59.24%	0.05924%	0.1448	0.0093
94	59.87%	0.05987%	0.1464	0.0091
95	60.51%	0.06051%	0.1479	0.0089
96	61.15%	0.06115%	0.1495	0.0088
97	61.78%	0.06178%	0.1511	0.0086
98	62.42%	0.06242%	0.1526	0.0084
99	63.06%	0.06306%	0.1542	0.0083
100	63.69%	0.06369%	0.1557	0.0081
101	64.33%	0.06433%	0.1573	0.0079
102	64.97%	0.06497%	0.1588	0.0078
103	65.61%	0.06561%	0.1604	0.0076
104	66.24%	0.06624%	0.1620	0.0075
105	66.88%	0.06688%	0.1635	0.0073
106	67.52%	0.06752%	0.1651	0.0072
107	68.15%	0.06815%	0.1666	0.0070
108	68.79%	0.06879%	0.1682	0.0069
109	69.43%	0.06943%	0.1697	0.0068
110	70.06%	0.07006%	0.1713	0.0066
111	70.70%	0.07070%	0.1729	0.0065
112	71.34%	0.07134%	0.1744	0.0064
113	71.97%	0.07197%	0.1760	0.0062
114	72.61%	0.07261%	0.1775	0.0061
115	73.25%	0.07325%	0.1791	0.0060
116	73.89%	0.07389%	0.1806	0.0059
117	74.52%	0.07452%	0.1822	0.0057
118	75.16%	0.07516%	0.1838	0.0056
119	75.80%	0.07580%	0.1853	0.0055
120	76.43%	0.07643%	0.1869	0.0054
121	77.07%	0.07707%	0.1884	0.0053
122	77.71%	0.07771%	0.1900	0.0052
123	78.34%	0.07834%	0.1916	0.0051
124	78.98%	0.07898%	0.1931	0.0049
125	79.62%	0.07962%	0.1947	0.0048
126	80.25%	0.08025%	0.1962	0.0047
127	80.89%	0.08089%	0.1978	0.0046
128	81.53%	0.08153%	0.1993	0.0045
129	82.17%	0.08217%	0.2009	0.0044
130	82.80%	0.08280%	0.2025	0.0043
131	83.44%	0.08344%	0.2040	0.0042
132	84.08%	0.08408%	0.2056	0.0042
133	84.71%	0.08471%	0.2071	0.0041
134	85.35%	0.08535%	0.2087	0.0040
135	85.99%	0.08599%	0.2102	0.0039
136	86.62%	0.08662%	0.2118	0.0038
137	87.26%	0.08726%	0.2134	0.0037

138	87.90%	0.08790%	0.2149	0.0036
139	88.54%	0.08854%	0.2165	0.0036
140	89.17%	0.08917%	0.2180	0.0035
141	89.81%	0.08981%	0.2196	0.0034
142	90.45%	0.09045%	0.2211	0.0033
143	91.08%	0.09108%	0.2227	0.0033
144	91.72%	0.09172%	0.2243	0.0032
145	92.36%	0.09236%	0.2258	0.0031
146	92.99%	0.09299%	0.2274	0.0030
147	93.63%	0.09363%	0.2289	0.0030
148	94.27%	0.09427%	0.2305	0.0029
149	94.90%	0.09490%	0.2320	0.0028
150	95.54%	0.09554%	0.2336	0.0028
151	96.18%	0.09618%	0.2352	0.0027
152	96.82%	0.09682%	0.2367	0.0026
153	97.45%	0.09745%	0.2383	0.0026
154	98.09%	0.09809%	0.2398	0.0025
155	98.73%	0.09873%	0.2414	0.0025
156	99.36%	0.09936%	0.2429	0.0024
157	100.00%	0.10000%	0.2445	0.0024
Beyond (e)				0.0787
Total				1.7651

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.00000%	0.0000	0.0000
18	0.57%	0.00057%	0.0016	0.0009
19	1.15%	0.00115%	0.0031	0.0018
20	1.72%	0.00172%	0.0047	0.0026
21	2.30%	0.00230%	0.0062	0.0033
22	2.87%	0.00287%	0.0078	0.0041
23	3.45%	0.00345%	0.0093	0.0047
24	4.02%	0.00402%	0.0109	0.0054
25	4.60%	0.00460%	0.0124	0.0059
26	5.17%	0.00517%	0.0140	0.0065
27	5.75%	0.00575%	0.0155	0.0070
28	6.32%	0.00632%	0.0171	0.0075
29	6.90%	0.00690%	0.0187	0.0079
30	7.47%	0.00747%	0.0202	0.0083
31	8.05%	0.00805%	0.0218	0.0087
32	8.62%	0.00862%	0.0233	0.0091
33	9.20%	0.00920%	0.0249	0.0094
34	9.77%	0.00977%	0.0264	0.0097
35	10.34%	0.01034%	0.0280	0.0099
36	10.92%	0.01092%	0.0295	0.0102
37	11.49%	0.01149%	0.0311	0.0104

38	12.07%	0.01207%	0.0326	0.0106
39	12.64%	0.01264%	0.0342	0.0108
40	13.22%	0.01322%	0.0358	0.0110
41	13.79%	0.01379%	0.0373	0.0111
42	14.37%	0.01437%	0.0389	0.0112
43	14.94%	0.01494%	0.0404	0.0113
44	15.52%	0.01552%	0.0420	0.0114
45	16.09%	0.01609%	0.0435	0.0115
46	16.67%	0.01667%	0.0451	0.0116
47	17.24%	0.01724%	0.0466	0.0116
48	17.82%	0.01782%	0.0482	0.0117
49	18.39%	0.01839%	0.0497	0.0117
50	18.97%	0.01897%	0.0513	0.0117
51	19.54%	0.01954%	0.0529	0.0117
52	20.11%	0.02011%	0.0544	0.0117
53	20.69%	0.02069%	0.0560	0.0117
54	21.26%	0.02126%	0.0575	0.0117
55	21.84%	0.02184%	0.0591	0.0116
56	22.41%	0.02241%	0.0606	0.0116
57	22.99%	0.02299%	0.0622	0.0115
58	23.56%	0.02356%	0.0637	0.0115
59	24.14%	0.02414%	0.0653	0.0114
60	24.71%	0.02471%	0.0668	0.0113
61	25.29%	0.02529%	0.0684	0.0113
62	25.86%	0.02586%	0.0700	0.0112
63	26.44%	0.02644%	0.0715	0.0111
64	27.01%	0.02701%	0.0731	0.0110
65	27.59%	0.02759%	0.0746	0.0109
66	28.16%	0.02816%	0.0762	0.0108
67	28.74%	0.02874%	0.0777	0.0107
68	29.31%	0.02931%	0.0793	0.0106
69	29.89%	0.02989%	0.0808	0.0105
70	30.46%	0.03046%	0.0824	0.0104
71	31.03%	0.03103%	0.0839	0.0103
72	31.61%	0.03161%	0.0855	0.0102
73	32.18%	0.03218%	0.0871	0.0101
74	32.76%	0.03276%	0.0886	0.0099
75	33.33%	0.03333%	0.0902	0.0098
76	33.91%	0.03391%	0.0917	0.0097
77	34.48%	0.03448%	0.0933	0.0096
78	35.06%	0.03506%	0.0948	0.0095
79	35.63%	0.03563%	0.0964	0.0093
80	36.21%	0.03621%	0.0979	0.0092
81	36.78%	0.03678%	0.0995	0.0091
82	37.36%	0.03736%	0.1010	0.0090
83	37.93%	0.03793%	0.1026	0.0088
84	38.51%	0.03851%	0.1042	0.0087
85	39.08%	0.03908%	0.1057	0.0086
86	39.66%	0.03966%	0.1073	0.0084
87	40.23%	0.04023%	0.1088	0.0083
88	40.80%	0.04080%	0.1104	0.0082
89	41.38%	0.04138%	0.1119	0.0081

90	41.95%	0.04195%	0.1135	0.0079
91	42.53%	0.04253%	0.1150	0.0078
92	43.10%	0.04310%	0.1166	0.0077
93	43.68%	0.04368%	0.1181	0.0076
94	44.25%	0.04425%	0.1197	0.0074
95	44.83%	0.04483%	0.1213	0.0073
96	45.40%	0.04540%	0.1228	0.0072
97	45.98%	0.04598%	0.1244	0.0071
98	46.55%	0.04655%	0.1259	0.0070
99	47.13%	0.04713%	0.1275	0.0068
100	47.70%	0.04770%	0.1290	0.0067
101	48.28%	0.04828%	0.1306	0.0066
102	48.85%	0.04885%	0.1321	0.0065
103	49.43%	0.04943%	0.1337	0.0064
104	50.00%	0.05000%	0.1353	0.0063
105	50.57%	0.05057%	0.1368	0.0061
106	51.15%	0.05115%	0.1384	0.0060
107	51.72%	0.05172%	0.1399	0.0059
108	52.30%	0.05230%	0.1415	0.0058
109	52.87%	0.05287%	0.1430	0.0057
110	53.45%	0.05345%	0.1446	0.0056
111	54.02%	0.05402%	0.1461	0.0055
112	54.60%	0.05460%	0.1477	0.0054
113	55.17%	0.05517%	0.1492	0.0053
114	55.75%	0.05575%	0.1508	0.0052
115	56.32%	0.05632%	0.1524	0.0051
116	56.90%	0.05690%	0.1539	0.0050
117	57.47%	0.05747%	0.1555	0.0049
118	58.05%	0.05805%	0.1570	0.0048
119	58.62%	0.05862%	0.1586	0.0047
120	59.20%	0.05920%	0.1601	0.0046
121	59.77%	0.05977%	0.1617	0.0045
122	60.34%	0.06034%	0.1632	0.0044
123	60.92%	0.06092%	0.1648	0.0043
124	61.49%	0.06149%	0.1663	0.0043
125	62.07%	0.06207%	0.1679	0.0042
126	62.64%	0.06264%	0.1695	0.0041
127	63.22%	0.06322%	0.1710	0.0040
128	63.79%	0.06379%	0.1726	0.0039
129	64.37%	0.06437%	0.1741	0.0038
130	64.94%	0.06494%	0.1757	0.0038
131	65.52%	0.06552%	0.1772	0.0037
132	66.09%	0.06609%	0.1788	0.0036
133	66.67%	0.06667%	0.1803	0.0035
134	67.24%	0.06724%	0.1819	0.0035
135	67.82%	0.06782%	0.1834	0.0034
136	68.39%	0.06839%	0.1850	0.0033
137	68.97%	0.06897%	0.1866	0.0033
138	69.54%	0.06954%	0.1881	0.0032
139	70.11%	0.07011%	0.1897	0.0031
140	70.69%	0.07069%	0.1912	0.0031
141	71.26%	0.07126%	0.1928	0.0030

142	71.84%	0.07184%	0.1943	0.0029
143	72.41%	0.07241%	0.1959	0.0029
144	72.99%	0.07299%	0.1974	0.0028
145	73.56%	0.07356%	0.1990	0.0027
146	74.14%	0.07414%	0.2005	0.0027
147	74.71%	0.07471%	0.2021	0.0026
148	75.29%	0.07529%	0.2037	0.0026
149	75.86%	0.07586%	0.2052	0.0025
150	76.44%	0.07644%	0.2068	0.0025
151	77.01%	0.07701%	0.2083	0.0024
152	77.59%	0.07759%	0.2099	0.0023
153	78.16%	0.07816%	0.2114	0.0023
154	78.74%	0.07874%	0.2130	0.0022
155	79.31%	0.07931%	0.2145	0.0022
156	79.89%	0.07989%	0.2161	0.0021
157	80.46%	0.08046%	0.2176	0.0021
158	81.03%	0.08103%	0.2192	0.0021
159	81.61%	0.08161%	0.2208	0.0020
160	82.18%	0.08218%	0.2223	0.0020
161	82.76%	0.08276%	0.2239	0.0019
162	83.33%	0.08333%	0.2254	0.0019
163	83.91%	0.08391%	0.2270	0.0018
164	84.48%	0.08448%	0.2285	0.0018
165	85.06%	0.08506%	0.2301	0.0018
166	85.63%	0.08563%	0.2316	0.0017
167	86.21%	0.08621%	0.2332	0.0017
168	86.78%	0.08678%	0.2347	0.0016
169	87.36%	0.08736%	0.2363	0.0016
170	87.93%	0.08793%	0.2379	0.0016
171	88.51%	0.08851%	0.2394	0.0015
172	89.08%	0.08908%	0.2410	0.0015
173	89.66%	0.08966%	0.2425	0.0015
174	90.23%	0.09023%	0.2441	0.0014
175	90.80%	0.09080%	0.2456	0.0014
176	91.38%	0.09138%	0.2472	0.0014
177	91.95%	0.09195%	0.2487	0.0013
178	92.53%	0.09253%	0.2503	0.0013
179	93.10%	0.09310%	0.2518	0.0013
180	93.68%	0.09368%	0.2534	0.0012
181	94.25%	0.09425%	0.2550	0.0012
182	94.83%	0.09483%	0.2565	0.0012
183	95.40%	0.09540%	0.2581	0.0012
184	95.98%	0.09598%	0.2596	0.0011
185	96.55%	0.09655%	0.2612	0.0011
186	97.13%	0.09713%	0.2627	0.0011
187	97.70%	0.09770%	0.2643	0.0011
188	98.28%	0.09828%	0.2658	0.0010
189	98.85%	0.09885%	0.2674	0.0010
190	99.43%	0.09943%	0.2689	0.0010
191	100.00%	0.10000%	0.2705	0.0010
Beyond (f)				0.0319
Total				1.0701

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.0000	0.0000
1	0.57%	0.00057%	0.0016	0.0015
2	1.15%	0.00115%	0.0031	0.0029
3	1.72%	0.00172%	0.0047	0.0043
4	2.30%	0.00230%	0.0062	0.0055
5	2.87%	0.00287%	0.0078	0.0067
6	3.45%	0.00345%	0.0093	0.0078
7	4.02%	0.00402%	0.0109	0.0088
8	4.60%	0.00460%	0.0124	0.0098
9	5.17%	0.00517%	0.0140	0.0107
10	5.75%	0.00575%	0.0155	0.0116
11	6.32%	0.00632%	0.0171	0.0124
12	6.90%	0.00690%	0.0187	0.0131
13	7.47%	0.00747%	0.0202	0.0138
14	8.05%	0.00805%	0.0218	0.0144
15	8.62%	0.00862%	0.0233	0.0150
16	9.20%	0.00920%	0.0249	0.0155
17	9.77%	0.00977%	0.0264	0.0160
18	10.34%	0.01034%	0.0280	0.0164
19	10.92%	0.01092%	0.0295	0.0168
20	11.49%	0.01149%	0.0311	0.0172
21	12.07%	0.01207%	0.0326	0.0175
22	12.64%	0.01264%	0.0342	0.0178
23	13.22%	0.01322%	0.0358	0.0181
24	13.79%	0.01379%	0.0373	0.0184
25	14.37%	0.01437%	0.0389	0.0186
26	14.94%	0.01494%	0.0404	0.0187
27	15.52%	0.01552%	0.0420	0.0189
28	16.09%	0.01609%	0.0435	0.0190
29	16.67%	0.01667%	0.0451	0.0191
30	17.24%	0.01724%	0.0466	0.0192
31	17.82%	0.01782%	0.0482	0.0193
32	18.39%	0.01839%	0.0497	0.0193
33	18.97%	0.01897%	0.0513	0.0193
34	19.54%	0.01954%	0.0529	0.0193
35	20.11%	0.02011%	0.0544	0.0193
36	20.69%	0.02069%	0.0560	0.0193
37	21.26%	0.02126%	0.0575	0.0193
38	21.84%	0.02184%	0.0591	0.0192
39	22.41%	0.02241%	0.0606	0.0191
40	22.99%	0.02299%	0.0622	0.0191
41	23.56%	0.02356%	0.0637	0.0190
42	24.14%	0.02414%	0.0653	0.0189

43	24.71%	0.02471%	0.0668	0.0188
44	25.29%	0.02529%	0.0684	0.0186
45	25.86%	0.02586%	0.0700	0.0185
46	26.44%	0.02644%	0.0715	0.0184
47	27.01%	0.02701%	0.0731	0.0182
48	27.59%	0.02759%	0.0746	0.0181
49	28.16%	0.02816%	0.0762	0.0179
50	28.74%	0.02874%	0.0777	0.0177
51	29.31%	0.02931%	0.0793	0.0176
52	29.89%	0.02989%	0.0808	0.0174
53	30.46%	0.03046%	0.0824	0.0172
54	31.03%	0.03103%	0.0839	0.0170
55	31.61%	0.03161%	0.0855	0.0168
56	32.18%	0.03218%	0.0871	0.0166
57	32.76%	0.03276%	0.0886	0.0164
58	33.33%	0.03333%	0.0902	0.0162
59	33.91%	0.03391%	0.0917	0.0160
60	34.48%	0.03448%	0.0933	0.0158
61	35.06%	0.03506%	0.0948	0.0156
62	35.63%	0.03563%	0.0964	0.0154
63	36.21%	0.03621%	0.0979	0.0152
64	36.78%	0.03678%	0.0995	0.0150
65	37.36%	0.03736%	0.1010	0.0148
66	37.93%	0.03793%	0.1026	0.0146
67	38.51%	0.03851%	0.1042	0.0144
68	39.08%	0.03908%	0.1057	0.0142
69	39.66%	0.03966%	0.1073	0.0140
70	40.23%	0.04023%	0.1088	0.0137
71	40.80%	0.04080%	0.1104	0.0135
72	41.38%	0.04138%	0.1119	0.0133
73	41.95%	0.04195%	0.1135	0.0131
74	42.53%	0.04253%	0.1150	0.0129
75	43.10%	0.04310%	0.1166	0.0127
76	43.68%	0.04368%	0.1181	0.0125
77	44.25%	0.04425%	0.1197	0.0123
78	44.83%	0.04483%	0.1213	0.0121
79	45.40%	0.04540%	0.1228	0.0119
80	45.98%	0.04598%	0.1244	0.0117
81	46.55%	0.04655%	0.1259	0.0115
82	47.13%	0.04713%	0.1275	0.0113
83	47.70%	0.04770%	0.1290	0.0111
84	48.28%	0.04828%	0.1306	0.0109
85	48.85%	0.04885%	0.1321	0.0107
86	49.43%	0.04943%	0.1337	0.0105
87	50.00%	0.05000%	0.1353	0.0103
88	50.57%	0.05057%	0.1368	0.0101
89	51.15%	0.05115%	0.1384	0.0100
90	51.72%	0.05172%	0.1399	0.0098
91	52.30%	0.05230%	0.1415	0.0096
92	52.87%	0.05287%	0.1430	0.0094
93	53.45%	0.05345%	0.1446	0.0093
94	54.02%	0.05402%	0.1461	0.0091

95	54.60%	0.05460%	0.1477	0.0089
96	55.17%	0.05517%	0.1492	0.0087
97	55.75%	0.05575%	0.1508	0.0086
98	56.32%	0.05632%	0.1524	0.0084
99	56.90%	0.05690%	0.1539	0.0082
100	57.47%	0.05747%	0.1555	0.0081
101	58.05%	0.05805%	0.1570	0.0079
102	58.62%	0.05862%	0.1586	0.0078
103	59.20%	0.05920%	0.1601	0.0076
104	59.77%	0.05977%	0.1617	0.0075
105	60.34%	0.06034%	0.1632	0.0073
106	60.92%	0.06092%	0.1648	0.0072
107	61.49%	0.06149%	0.1663	0.0070
108	62.07%	0.06207%	0.1679	0.0069
109	62.64%	0.06264%	0.1695	0.0068
110	63.22%	0.06322%	0.1710	0.0066
111	63.79%	0.06379%	0.1726	0.0065
112	64.37%	0.06437%	0.1741	0.0064
113	64.94%	0.06494%	0.1757	0.0062
114	65.52%	0.06552%	0.1772	0.0061
115	66.09%	0.06609%	0.1788	0.0060
116	66.67%	0.06667%	0.1803	0.0058
117	67.24%	0.06724%	0.1819	0.0057
118	67.82%	0.06782%	0.1834	0.0056
119	68.39%	0.06839%	0.1850	0.0055
120	68.97%	0.06897%	0.1866	0.0054
121	69.54%	0.06954%	0.1881	0.0053
122	70.11%	0.07011%	0.1897	0.0052
123	70.69%	0.07069%	0.1912	0.0050
124	71.26%	0.07126%	0.1928	0.0049
125	71.84%	0.07184%	0.1943	0.0048
126	72.41%	0.07241%	0.1959	0.0047
127	72.99%	0.07299%	0.1974	0.0046
128	73.56%	0.07356%	0.1990	0.0045
129	74.14%	0.07414%	0.2005	0.0044
130	74.71%	0.07471%	0.2021	0.0043
131	75.29%	0.07529%	0.2037	0.0042
132	75.86%	0.07586%	0.2052	0.0041
133	76.44%	0.07644%	0.2068	0.0041
134	77.01%	0.07701%	0.2083	0.0040
135	77.59%	0.07759%	0.2099	0.0039
136	78.16%	0.07816%	0.2114	0.0038
137	78.74%	0.07874%	0.2130	0.0037
138	79.31%	0.07931%	0.2145	0.0036
139	79.89%	0.07989%	0.2161	0.0036
140	80.46%	0.08046%	0.2176	0.0035
141	81.03%	0.08103%	0.2192	0.0034
142	81.61%	0.08161%	0.2208	0.0033
143	82.18%	0.08218%	0.2223	0.0032
144	82.76%	0.08276%	0.2239	0.0032
145	83.33%	0.08333%	0.2254	0.0031
146	83.91%	0.08391%	0.2270	0.0030

147	84.48%	0.08448%	0.2285	0.0030
148	85.06%	0.08506%	0.2301	0.0029
149	85.63%	0.08563%	0.2316	0.0028
150	86.21%	0.08621%	0.2332	0.0028
151	86.78%	0.08678%	0.2347	0.0027
152	87.36%	0.08736%	0.2363	0.0026
153	87.93%	0.08793%	0.2379	0.0026
154	88.51%	0.08851%	0.2394	0.0025
155	89.08%	0.08908%	0.2410	0.0025
156	89.66%	0.08966%	0.2425	0.0024
157	90.23%	0.09023%	0.2441	0.0024
158	90.80%	0.09080%	0.2456	0.0023
159	91.38%	0.09138%	0.2472	0.0022
160	91.95%	0.09195%	0.2487	0.0022
161	92.53%	0.09253%	0.2503	0.0021
162	93.10%	0.09310%	0.2518	0.0021
163	93.68%	0.09368%	0.2534	0.0020
164	94.25%	0.09425%	0.2550	0.0020
165	94.83%	0.09483%	0.2565	0.0020
166	95.40%	0.09540%	0.2581	0.0019
167	95.98%	0.09598%	0.2596	0.0019
168	96.55%	0.09655%	0.2612	0.0018
169	97.13%	0.09713%	0.2627	0.0018
170	97.70%	0.09770%	0.2643	0.0017
171	98.28%	0.09828%	0.2658	0.0017
172	98.85%	0.09885%	0.2674	0.0017
173	99.43%	0.09943%	0.2689	0.0016
174	100.00%	0.10000%	0.2705	0.0016
Beyond (g)				0.0526
Total				1.7688

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%

20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	6.32
Lake Ashtabula - Jump Dispersal (acres):	7.16
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.0801
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.0486
Lower Sheyenne River - Jump Dispersal (river-miles):	0.0803

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 158 into perpetuity

(f) From year 192 into perpetuity

(g) From year 175 into perpetuity

(h) From year 26 into perpetuity

Appendix 2E. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Slow Invasion - High Risk (One Organism)

Probability of successful invasion:	1.00E-02
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.000	0.000
1	5.88%	0.0588%	3.079	2.989
2	11.76%	0.1176%	6.158	5.804
3	17.65%	0.1765%	9.236	8.453
4	23.53%	0.2353%	12.315	10.942
5	29.41%	0.2941%	15.394	13.279
6	35.29%	0.3529%	18.473	15.471
7	41.18%	0.4118%	21.552	17.524
8	47.06%	0.4706%	24.631	19.444
9	52.94%	0.5294%	27.709	21.237
10	58.82%	0.5882%	30.788	22.909
11	64.71%	0.6471%	33.867	24.466
12	70.59%	0.7059%	36.946	25.913
13	76.47%	0.7647%	40.025	27.255
14	82.35%	0.8235%	43.104	28.497
15	88.24%	0.8824%	46.182	29.643
16	94.12%	0.9412%	49.261	30.698
17	100.00%	1.0000%	52.340	31.667
Beyond (c)				1,055.552
Total				1,391.741

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.000	0.000
1	12.50%	0.1250%	6.543	6.352

2	25.00%	0.2500%	13.085	12.334
3	37.50%	0.3750%	19.628	17.962
4	50.00%	0.5000%	26.170	23.252
5	62.50%	0.6250%	32.713	28.218
6	75.00%	0.7500%	39.255	32.875
7	87.50%	0.8750%	45.798	37.238
8	100.00%	1.0000%	52.340	41.318
Beyond (d)				1,377.256
Total				1,576.804

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.000	0.000
1	0.64%	0.0064%	0.016	0.015
2	1.27%	0.0127%	0.031	0.029
3	1.91%	0.0191%	0.047	0.043
4	2.55%	0.0255%	0.062	0.055
5	3.18%	0.0318%	0.078	0.067
6	3.82%	0.0382%	0.093	0.078
7	4.46%	0.0446%	0.109	0.089
8	5.10%	0.0510%	0.125	0.098
9	5.73%	0.0573%	0.140	0.107
10	6.37%	0.0637%	0.156	0.116
11	7.01%	0.0701%	0.171	0.124
12	7.64%	0.0764%	0.187	0.131
13	8.28%	0.0828%	0.202	0.138
14	8.92%	0.0892%	0.218	0.144
15	9.55%	0.0955%	0.234	0.150
16	10.19%	0.1019%	0.249	0.155
17	10.83%	0.1083%	0.265	0.160
18	11.46%	0.1146%	0.280	0.165
19	12.10%	0.1210%	0.296	0.169
20	12.74%	0.1274%	0.311	0.172
21	13.38%	0.1338%	0.327	0.176
22	14.01%	0.1401%	0.343	0.179
23	14.65%	0.1465%	0.358	0.181
24	15.29%	0.1529%	0.374	0.184
25	15.92%	0.1592%	0.389	0.186
26	16.56%	0.1656%	0.405	0.188
27	17.20%	0.1720%	0.420	0.189
28	17.83%	0.1783%	0.436	0.191
29	18.47%	0.1847%	0.452	0.192
30	19.11%	0.1911%	0.467	0.192
31	19.75%	0.1975%	0.483	0.193
32	20.38%	0.2038%	0.498	0.194
33	21.02%	0.2102%	0.514	0.194

34	21.66%	0.2166%	0.529	0.194
35	22.29%	0.2229%	0.545	0.194
36	22.93%	0.2293%	0.561	0.193
37	23.57%	0.2357%	0.576	0.193
38	24.20%	0.2420%	0.592	0.192
39	24.84%	0.2484%	0.607	0.192
40	25.48%	0.2548%	0.623	0.191
41	26.11%	0.2611%	0.639	0.190
42	26.75%	0.2675%	0.654	0.189
43	27.39%	0.2739%	0.670	0.188
44	28.03%	0.2803%	0.685	0.187
45	28.66%	0.2866%	0.701	0.185
46	29.30%	0.2930%	0.716	0.184
47	29.94%	0.2994%	0.732	0.182
48	30.57%	0.3057%	0.748	0.181
49	31.21%	0.3121%	0.763	0.179
50	31.85%	0.3185%	0.779	0.178
51	32.48%	0.3248%	0.794	0.176
52	33.12%	0.3312%	0.810	0.174
53	33.76%	0.3376%	0.825	0.172
54	34.39%	0.3439%	0.841	0.170
55	35.03%	0.3503%	0.857	0.169
56	35.67%	0.3567%	0.872	0.167
57	36.31%	0.3631%	0.888	0.165
58	36.94%	0.3694%	0.903	0.163
59	37.58%	0.3758%	0.919	0.161
60	38.22%	0.3822%	0.934	0.159
61	38.85%	0.3885%	0.950	0.157
62	39.49%	0.3949%	0.966	0.154
63	40.13%	0.4013%	0.981	0.152
64	40.76%	0.4076%	0.997	0.150
65	41.40%	0.4140%	1.012	0.148
66	42.04%	0.4204%	1.028	0.146
67	42.68%	0.4268%	1.043	0.144
68	43.31%	0.4331%	1.059	0.142
69	43.95%	0.4395%	1.075	0.140
70	44.59%	0.4459%	1.090	0.138
71	45.22%	0.4522%	1.106	0.136
72	45.86%	0.4586%	1.121	0.133
73	46.50%	0.4650%	1.137	0.131
74	47.13%	0.4713%	1.152	0.129
75	47.77%	0.4777%	1.168	0.127
76	48.41%	0.4841%	1.184	0.125
77	49.04%	0.4904%	1.199	0.123
78	49.68%	0.4968%	1.215	0.121
79	50.32%	0.5032%	1.230	0.119
80	50.96%	0.5096%	1.246	0.117
81	51.59%	0.5159%	1.261	0.115
82	52.23%	0.5223%	1.277	0.113
83	52.87%	0.5287%	1.293	0.111
84	53.50%	0.5350%	1.308	0.109
85	54.14%	0.5414%	1.324	0.107

86	54.78%	0.5478%	1.339	0.105
87	55.41%	0.5541%	1.355	0.104
88	56.05%	0.5605%	1.370	0.102
89	56.69%	0.5669%	1.386	0.100
90	57.32%	0.5732%	1.402	0.098
91	57.96%	0.5796%	1.417	0.096
92	58.60%	0.5860%	1.433	0.094
93	59.24%	0.5924%	1.448	0.093
94	59.87%	0.5987%	1.464	0.091
95	60.51%	0.6051%	1.479	0.089
96	61.15%	0.6115%	1.495	0.088
97	61.78%	0.6178%	1.511	0.086
98	62.42%	0.6242%	1.526	0.084
99	63.06%	0.6306%	1.542	0.083
100	63.69%	0.6369%	1.557	0.081
101	64.33%	0.6433%	1.573	0.079
102	64.97%	0.6497%	1.588	0.078
103	65.61%	0.6561%	1.604	0.076
104	66.24%	0.6624%	1.620	0.075
105	66.88%	0.6688%	1.635	0.073
106	67.52%	0.6752%	1.651	0.072
107	68.15%	0.6815%	1.666	0.070
108	68.79%	0.6879%	1.682	0.069
109	69.43%	0.6943%	1.697	0.068
110	70.06%	0.7006%	1.713	0.066
111	70.70%	0.7070%	1.729	0.065
112	71.34%	0.7134%	1.744	0.064
113	71.97%	0.7197%	1.760	0.062
114	72.61%	0.7261%	1.775	0.061
115	73.25%	0.7325%	1.791	0.060
116	73.89%	0.7389%	1.806	0.059
117	74.52%	0.7452%	1.822	0.057
118	75.16%	0.7516%	1.838	0.056
119	75.80%	0.7580%	1.853	0.055
120	76.43%	0.7643%	1.869	0.054
121	77.07%	0.7707%	1.884	0.053
122	77.71%	0.7771%	1.900	0.052
123	78.34%	0.7834%	1.916	0.051
124	78.98%	0.7898%	1.931	0.049
125	79.62%	0.7962%	1.947	0.048
126	80.25%	0.8025%	1.962	0.047
127	80.89%	0.8089%	1.978	0.046
128	81.53%	0.8153%	1.993	0.045
129	82.17%	0.8217%	2.009	0.044
130	82.80%	0.8280%	2.025	0.043
131	83.44%	0.8344%	2.040	0.042
132	84.08%	0.8408%	2.056	0.042
133	84.71%	0.8471%	2.071	0.041
134	85.35%	0.8535%	2.087	0.040
135	85.99%	0.8599%	2.102	0.039
136	86.62%	0.8662%	2.118	0.038
137	87.26%	0.8726%	2.134	0.037

138	87.90%	0.8790%	2.149	0.036
139	88.54%	0.8854%	2.165	0.036
140	89.17%	0.8917%	2.180	0.035
141	89.81%	0.8981%	2.196	0.034
142	90.45%	0.9045%	2.211	0.033
143	91.08%	0.9108%	2.227	0.033
144	91.72%	0.9172%	2.243	0.032
145	92.36%	0.9236%	2.258	0.031
146	92.99%	0.9299%	2.274	0.030
147	93.63%	0.9363%	2.289	0.030
148	94.27%	0.9427%	2.305	0.029
149	94.90%	0.9490%	2.320	0.028
150	95.54%	0.9554%	2.336	0.028
151	96.18%	0.9618%	2.352	0.027
152	96.82%	0.9682%	2.367	0.026
153	97.45%	0.9745%	2.383	0.026
154	98.09%	0.9809%	2.398	0.025
155	98.73%	0.9873%	2.414	0.025
156	99.36%	0.9936%	2.429	0.024
157	100.00%	1.0000%	2.445	0.024
Beyond (e)				0.787
Total				17.651

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.0000%	0.000	0.000
18	0.57%	0.0057%	0.016	0.009
19	1.15%	0.0115%	0.031	0.018
20	1.72%	0.0172%	0.047	0.026
21	2.30%	0.0230%	0.062	0.033
22	2.87%	0.0287%	0.078	0.041
23	3.45%	0.0345%	0.093	0.047
24	4.02%	0.0402%	0.109	0.054
25	4.60%	0.0460%	0.124	0.059
26	5.17%	0.0517%	0.140	0.065
27	5.75%	0.0575%	0.155	0.070
28	6.32%	0.0632%	0.171	0.075
29	6.90%	0.0690%	0.187	0.079
30	7.47%	0.0747%	0.202	0.083
31	8.05%	0.0805%	0.218	0.087
32	8.62%	0.0862%	0.233	0.091
33	9.20%	0.0920%	0.249	0.094
34	9.77%	0.0977%	0.264	0.097
35	10.34%	0.1034%	0.280	0.099
36	10.92%	0.1092%	0.295	0.102
37	11.49%	0.1149%	0.311	0.104

38	12.07%	0.1207%	0.326	0.106
39	12.64%	0.1264%	0.342	0.108
40	13.22%	0.1322%	0.358	0.110
41	13.79%	0.1379%	0.373	0.111
42	14.37%	0.1437%	0.389	0.112
43	14.94%	0.1494%	0.404	0.113
44	15.52%	0.1552%	0.420	0.114
45	16.09%	0.1609%	0.435	0.115
46	16.67%	0.1667%	0.451	0.116
47	17.24%	0.1724%	0.466	0.116
48	17.82%	0.1782%	0.482	0.117
49	18.39%	0.1839%	0.497	0.117
50	18.97%	0.1897%	0.513	0.117
51	19.54%	0.1954%	0.529	0.117
52	20.11%	0.2011%	0.544	0.117
53	20.69%	0.2069%	0.560	0.117
54	21.26%	0.2126%	0.575	0.117
55	21.84%	0.2184%	0.591	0.116
56	22.41%	0.2241%	0.606	0.116
57	22.99%	0.2299%	0.622	0.115
58	23.56%	0.2356%	0.637	0.115
59	24.14%	0.2414%	0.653	0.114
60	24.71%	0.2471%	0.668	0.113
61	25.29%	0.2529%	0.684	0.113
62	25.86%	0.2586%	0.700	0.112
63	26.44%	0.2644%	0.715	0.111
64	27.01%	0.2701%	0.731	0.110
65	27.59%	0.2759%	0.746	0.109
66	28.16%	0.2816%	0.762	0.108
67	28.74%	0.2874%	0.777	0.107
68	29.31%	0.2931%	0.793	0.106
69	29.89%	0.2989%	0.808	0.105
70	30.46%	0.3046%	0.824	0.104
71	31.03%	0.3103%	0.839	0.103
72	31.61%	0.3161%	0.855	0.102
73	32.18%	0.3218%	0.871	0.101
74	32.76%	0.3276%	0.886	0.099
75	33.33%	0.3333%	0.902	0.098
76	33.91%	0.3391%	0.917	0.097
77	34.48%	0.3448%	0.933	0.096
78	35.06%	0.3506%	0.948	0.095
79	35.63%	0.3563%	0.964	0.093
80	36.21%	0.3621%	0.979	0.092
81	36.78%	0.3678%	0.995	0.091
82	37.36%	0.3736%	1.010	0.090
83	37.93%	0.3793%	1.026	0.088
84	38.51%	0.3851%	1.042	0.087
85	39.08%	0.3908%	1.057	0.086
86	39.66%	0.3966%	1.073	0.084
87	40.23%	0.4023%	1.088	0.083
88	40.80%	0.4080%	1.104	0.082
89	41.38%	0.4138%	1.119	0.081

90	41.95%	0.4195%	1.135	0.079
91	42.53%	0.4253%	1.150	0.078
92	43.10%	0.4310%	1.166	0.077
93	43.68%	0.4368%	1.181	0.076
94	44.25%	0.4425%	1.197	0.074
95	44.83%	0.4483%	1.213	0.073
96	45.40%	0.4540%	1.228	0.072
97	45.98%	0.4598%	1.244	0.071
98	46.55%	0.4655%	1.259	0.070
99	47.13%	0.4713%	1.275	0.068
100	47.70%	0.4770%	1.290	0.067
101	48.28%	0.4828%	1.306	0.066
102	48.85%	0.4885%	1.321	0.065
103	49.43%	0.4943%	1.337	0.064
104	50.00%	0.5000%	1.353	0.063
105	50.57%	0.5057%	1.368	0.061
106	51.15%	0.5115%	1.384	0.060
107	51.72%	0.5172%	1.399	0.059
108	52.30%	0.5230%	1.415	0.058
109	52.87%	0.5287%	1.430	0.057
110	53.45%	0.5345%	1.446	0.056
111	54.02%	0.5402%	1.461	0.055
112	54.60%	0.5460%	1.477	0.054
113	55.17%	0.5517%	1.492	0.053
114	55.75%	0.5575%	1.508	0.052
115	56.32%	0.5632%	1.524	0.051
116	56.90%	0.5690%	1.539	0.050
117	57.47%	0.5747%	1.555	0.049
118	58.05%	0.5805%	1.570	0.048
119	58.62%	0.5862%	1.586	0.047
120	59.20%	0.5920%	1.601	0.046
121	59.77%	0.5977%	1.617	0.045
122	60.34%	0.6034%	1.632	0.044
123	60.92%	0.6092%	1.648	0.043
124	61.49%	0.6149%	1.663	0.043
125	62.07%	0.6207%	1.679	0.042
126	62.64%	0.6264%	1.695	0.041
127	63.22%	0.6322%	1.710	0.040
128	63.79%	0.6379%	1.726	0.039
129	64.37%	0.6437%	1.741	0.038
130	64.94%	0.6494%	1.757	0.038
131	65.52%	0.6552%	1.772	0.037
132	66.09%	0.6609%	1.788	0.036
133	66.67%	0.6667%	1.803	0.035
134	67.24%	0.6724%	1.819	0.035
135	67.82%	0.6782%	1.834	0.034
136	68.39%	0.6839%	1.850	0.033
137	68.97%	0.6897%	1.866	0.033
138	69.54%	0.6954%	1.881	0.032
139	70.11%	0.7011%	1.897	0.031
140	70.69%	0.7069%	1.912	0.031
141	71.26%	0.7126%	1.928	0.030

142	71.84%	0.7184%	1.943	0.029
143	72.41%	0.7241%	1.959	0.029
144	72.99%	0.7299%	1.974	0.028
145	73.56%	0.7356%	1.990	0.027
146	74.14%	0.7414%	2.005	0.027
147	74.71%	0.7471%	2.021	0.026
148	75.29%	0.7529%	2.037	0.026
149	75.86%	0.7586%	2.052	0.025
150	76.44%	0.7644%	2.068	0.025
151	77.01%	0.7701%	2.083	0.024
152	77.59%	0.7759%	2.099	0.023
153	78.16%	0.7816%	2.114	0.023
154	78.74%	0.7874%	2.130	0.022
155	79.31%	0.7931%	2.145	0.022
156	79.89%	0.7989%	2.161	0.021
157	80.46%	0.8046%	2.176	0.021
158	81.03%	0.8103%	2.192	0.021
159	81.61%	0.8161%	2.208	0.020
160	82.18%	0.8218%	2.223	0.020
161	82.76%	0.8276%	2.239	0.019
162	83.33%	0.8333%	2.254	0.019
163	83.91%	0.8391%	2.270	0.018
164	84.48%	0.8448%	2.285	0.018
165	85.06%	0.8506%	2.301	0.018
166	85.63%	0.8563%	2.316	0.017
167	86.21%	0.8621%	2.332	0.017
168	86.78%	0.8678%	2.347	0.016
169	87.36%	0.8736%	2.363	0.016
170	87.93%	0.8793%	2.379	0.016
171	88.51%	0.8851%	2.394	0.015
172	89.08%	0.8908%	2.410	0.015
173	89.66%	0.8966%	2.425	0.015
174	90.23%	0.9023%	2.441	0.014
175	90.80%	0.9080%	2.456	0.014
176	91.38%	0.9138%	2.472	0.014
177	91.95%	0.9195%	2.487	0.013
178	92.53%	0.9253%	2.503	0.013
179	93.10%	0.9310%	2.518	0.013
180	93.68%	0.9368%	2.534	0.012
181	94.25%	0.9425%	2.550	0.012
182	94.83%	0.9483%	2.565	0.012
183	95.40%	0.9540%	2.581	0.012
184	95.98%	0.9598%	2.596	0.011
185	96.55%	0.9655%	2.612	0.011
186	97.13%	0.9713%	2.627	0.011
187	97.70%	0.9770%	2.643	0.011
188	98.28%	0.9828%	2.658	0.010
189	98.85%	0.9885%	2.674	0.010
190	99.43%	0.9943%	2.689	0.010
191	100.00%	1.0000%	2.705	0.010
Beyond (f)				0.319
Total				10.701

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.000	0.000
1	0.57%	0.0057%	0.016	0.015
2	1.15%	0.0115%	0.031	0.029
3	1.72%	0.0172%	0.047	0.043
4	2.30%	0.0230%	0.062	0.055
5	2.87%	0.0287%	0.078	0.067
6	3.45%	0.0345%	0.093	0.078
7	4.02%	0.0402%	0.109	0.088
8	4.60%	0.0460%	0.124	0.098
9	5.17%	0.0517%	0.140	0.107
10	5.75%	0.0575%	0.155	0.116
11	6.32%	0.0632%	0.171	0.124
12	6.90%	0.0690%	0.187	0.131
13	7.47%	0.0747%	0.202	0.138
14	8.05%	0.0805%	0.218	0.144
15	8.62%	0.0862%	0.233	0.150
16	9.20%	0.0920%	0.249	0.155
17	9.77%	0.0977%	0.264	0.160
18	10.34%	0.1034%	0.280	0.164
19	10.92%	0.1092%	0.295	0.168
20	11.49%	0.1149%	0.311	0.172
21	12.07%	0.1207%	0.326	0.175
22	12.64%	0.1264%	0.342	0.178
23	13.22%	0.1322%	0.358	0.181
24	13.79%	0.1379%	0.373	0.184
25	14.37%	0.1437%	0.389	0.186
26	14.94%	0.1494%	0.404	0.187
27	15.52%	0.1552%	0.420	0.189
28	16.09%	0.1609%	0.435	0.190
29	16.67%	0.1667%	0.451	0.191
30	17.24%	0.1724%	0.466	0.192
31	17.82%	0.1782%	0.482	0.193
32	18.39%	0.1839%	0.497	0.193
33	18.97%	0.1897%	0.513	0.193
34	19.54%	0.1954%	0.529	0.193
35	20.11%	0.2011%	0.544	0.193
36	20.69%	0.2069%	0.560	0.193
37	21.26%	0.2126%	0.575	0.193
38	21.84%	0.2184%	0.591	0.192
39	22.41%	0.2241%	0.606	0.191
40	22.99%	0.2299%	0.622	0.191
41	23.56%	0.2356%	0.637	0.190
42	24.14%	0.2414%	0.653	0.189

43	24.71%	0.2471%	0.668	0.188
44	25.29%	0.2529%	0.684	0.186
45	25.86%	0.2586%	0.700	0.185
46	26.44%	0.2644%	0.715	0.184
47	27.01%	0.2701%	0.731	0.182
48	27.59%	0.2759%	0.746	0.181
49	28.16%	0.2816%	0.762	0.179
50	28.74%	0.2874%	0.777	0.177
51	29.31%	0.2931%	0.793	0.176
52	29.89%	0.2989%	0.808	0.174
53	30.46%	0.3046%	0.824	0.172
54	31.03%	0.3103%	0.839	0.170
55	31.61%	0.3161%	0.855	0.168
56	32.18%	0.3218%	0.871	0.166
57	32.76%	0.3276%	0.886	0.164
58	33.33%	0.3333%	0.902	0.162
59	33.91%	0.3391%	0.917	0.160
60	34.48%	0.3448%	0.933	0.158
61	35.06%	0.3506%	0.948	0.156
62	35.63%	0.3563%	0.964	0.154
63	36.21%	0.3621%	0.979	0.152
64	36.78%	0.3678%	0.995	0.150
65	37.36%	0.3736%	1.010	0.148
66	37.93%	0.3793%	1.026	0.146
67	38.51%	0.3851%	1.042	0.144
68	39.08%	0.3908%	1.057	0.142
69	39.66%	0.3966%	1.073	0.140
70	40.23%	0.4023%	1.088	0.137
71	40.80%	0.4080%	1.104	0.135
72	41.38%	0.4138%	1.119	0.133
73	41.95%	0.4195%	1.135	0.131
74	42.53%	0.4253%	1.150	0.129
75	43.10%	0.4310%	1.166	0.127
76	43.68%	0.4368%	1.181	0.125
77	44.25%	0.4425%	1.197	0.123
78	44.83%	0.4483%	1.213	0.121
79	45.40%	0.4540%	1.228	0.119
80	45.98%	0.4598%	1.244	0.117
81	46.55%	0.4655%	1.259	0.115
82	47.13%	0.4713%	1.275	0.113
83	47.70%	0.4770%	1.290	0.111
84	48.28%	0.4828%	1.306	0.109
85	48.85%	0.4885%	1.321	0.107
86	49.43%	0.4943%	1.337	0.105
87	50.00%	0.5000%	1.353	0.103
88	50.57%	0.5057%	1.368	0.101
89	51.15%	0.5115%	1.384	0.100
90	51.72%	0.5172%	1.399	0.098
91	52.30%	0.5230%	1.415	0.096
92	52.87%	0.5287%	1.430	0.094
93	53.45%	0.5345%	1.446	0.093
94	54.02%	0.5402%	1.461	0.091

95	54.60%	0.5460%	1.477	0.089
96	55.17%	0.5517%	1.492	0.087
97	55.75%	0.5575%	1.508	0.086
98	56.32%	0.5632%	1.524	0.084
99	56.90%	0.5690%	1.539	0.082
100	57.47%	0.5747%	1.555	0.081
101	58.05%	0.5805%	1.570	0.079
102	58.62%	0.5862%	1.586	0.078
103	59.20%	0.5920%	1.601	0.076
104	59.77%	0.5977%	1.617	0.075
105	60.34%	0.6034%	1.632	0.073
106	60.92%	0.6092%	1.648	0.072
107	61.49%	0.6149%	1.663	0.070
108	62.07%	0.6207%	1.679	0.069
109	62.64%	0.6264%	1.695	0.068
110	63.22%	0.6322%	1.710	0.066
111	63.79%	0.6379%	1.726	0.065
112	64.37%	0.6437%	1.741	0.064
113	64.94%	0.6494%	1.757	0.062
114	65.52%	0.6552%	1.772	0.061
115	66.09%	0.6609%	1.788	0.060
116	66.67%	0.6667%	1.803	0.058
117	67.24%	0.6724%	1.819	0.057
118	67.82%	0.6782%	1.834	0.056
119	68.39%	0.6839%	1.850	0.055
120	68.97%	0.6897%	1.866	0.054
121	69.54%	0.6954%	1.881	0.053
122	70.11%	0.7011%	1.897	0.052
123	70.69%	0.7069%	1.912	0.050
124	71.26%	0.7126%	1.928	0.049
125	71.84%	0.7184%	1.943	0.048
126	72.41%	0.7241%	1.959	0.047
127	72.99%	0.7299%	1.974	0.046
128	73.56%	0.7356%	1.990	0.045
129	74.14%	0.7414%	2.005	0.044
130	74.71%	0.7471%	2.021	0.043
131	75.29%	0.7529%	2.037	0.042
132	75.86%	0.7586%	2.052	0.041
133	76.44%	0.7644%	2.068	0.041
134	77.01%	0.7701%	2.083	0.040
135	77.59%	0.7759%	2.099	0.039
136	78.16%	0.7816%	2.114	0.038
137	78.74%	0.7874%	2.130	0.037
138	79.31%	0.7931%	2.145	0.036
139	79.89%	0.7989%	2.161	0.036
140	80.46%	0.8046%	2.176	0.035
141	81.03%	0.8103%	2.192	0.034
142	81.61%	0.8161%	2.208	0.033
143	82.18%	0.8218%	2.223	0.032
144	82.76%	0.8276%	2.239	0.032
145	83.33%	0.8333%	2.254	0.031
146	83.91%	0.8391%	2.270	0.030

147	84.48%	0.8448%	2.285	0.030
148	85.06%	0.8506%	2.301	0.029
149	85.63%	0.8563%	2.316	0.028
150	86.21%	0.8621%	2.332	0.028
151	86.78%	0.8678%	2.347	0.027
152	87.36%	0.8736%	2.363	0.026
153	87.93%	0.8793%	2.379	0.026
154	88.51%	0.8851%	2.394	0.025
155	89.08%	0.8908%	2.410	0.025
156	89.66%	0.8966%	2.425	0.024
157	90.23%	0.9023%	2.441	0.024
158	90.80%	0.9080%	2.456	0.023
159	91.38%	0.9138%	2.472	0.022
160	91.95%	0.9195%	2.487	0.022
161	92.53%	0.9253%	2.503	0.021
162	93.10%	0.9310%	2.518	0.021
163	93.68%	0.9368%	2.534	0.020
164	94.25%	0.9425%	2.550	0.020
165	94.83%	0.9483%	2.565	0.020
166	95.40%	0.9540%	2.581	0.019
167	95.98%	0.9598%	2.596	0.019
168	96.55%	0.9655%	2.612	0.018
169	97.13%	0.9713%	2.627	0.018
170	97.70%	0.9770%	2.643	0.017
171	98.28%	0.9828%	2.658	0.017
172	98.85%	0.9885%	2.674	0.017
173	99.43%	0.9943%	2.689	0.016
174	100.00%	1.0000%	2.705	0.016
Beyond (g)				0.526
Total				17.688

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%

20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	63.2
Lake Ashtabula - Jump Dispersal (acres):	71.6
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.801
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.486
Lower Sheyenne River - Jump Dispersal (river-miles):	0.803

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 158 into perpetuity

(f) From year 192 into perpetuity

(g) From year 175 into perpetuity

(h) From year 26 into perpetuity

Appendix 2F. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Slow Invasion - Very High Risk (One Organism)

Probability of successful invasion:	1.00E+00
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0.000	0.000
1	5.88%	5.88%	307.882	298.915
2	11.76%	11.76%	615.765	580.417
3	17.65%	17.65%	923.647	845.268
4	23.53%	23.53%	1,231.529	1,094.198
5	29.41%	29.41%	1,539.412	1,327.910
6	35.29%	35.29%	1,847.294	1,547.080
7	41.18%	41.18%	2,155.176	1,752.356
8	47.06%	47.06%	2,463.059	1,944.361
9	52.94%	52.94%	2,770.941	2,123.696
10	58.82%	58.82%	3,078.824	2,290.934
11	64.71%	64.71%	3,386.706	2,446.628
12	70.59%	70.59%	3,694.588	2,591.310
13	76.47%	76.47%	4,002.471	2,725.488
14	82.35%	82.35%	4,310.353	2,849.651
15	88.24%	88.24%	4,618.235	2,964.269
16	94.12%	94.12%	4,926.118	3,069.794
17	100.00%	100.00%	5,234.000	3,166.656
Beyond (c)				105,555.203
Total				139,174.133

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0.000	0.000
1	12.50%	12.50%	654.250	635.194

2	25.00%	25.00%	1,308.500	1,233.387
3	37.50%	37.50%	1,962.750	1,796.194
4	50.00%	50.00%	2,617.000	2,325.171
5	62.50%	62.50%	3,271.250	2,821.809
6	75.00%	75.00%	3,925.500	3,287.544
7	87.50%	87.50%	4,579.750	3,723.756
8	100.00%	100.00%	5,234.000	4,131.768
Beyond (d)				137,725.598
Total				157,680.421

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0.000	0.000
1	0.64%	0.64%	1.557	1.512
2	1.27%	1.27%	3.115	2.936
3	1.91%	1.91%	4.672	4.276
4	2.55%	2.55%	6.229	5.535
5	3.18%	3.18%	7.787	6.717
6	3.82%	3.82%	9.344	7.825
7	4.46%	4.46%	10.901	8.864
8	5.10%	5.10%	12.459	9.835
9	5.73%	5.73%	14.016	10.742
10	6.37%	6.37%	15.573	11.588
11	7.01%	7.01%	17.131	12.375
12	7.64%	7.64%	18.688	13.107
13	8.28%	8.28%	20.245	13.786
14	8.92%	8.92%	21.803	14.414
15	9.55%	9.55%	23.360	14.994
16	10.19%	10.19%	24.917	15.528
17	10.83%	10.83%	26.475	16.018
18	11.46%	11.46%	28.032	16.466
19	12.10%	12.10%	29.589	16.874
20	12.74%	12.74%	31.146	17.245
21	13.38%	13.38%	32.704	17.580
22	14.01%	14.01%	34.261	17.881
23	14.65%	14.65%	35.818	18.149
24	15.29%	15.29%	37.376	18.386
25	15.92%	15.92%	38.933	18.595
26	16.56%	16.56%	40.490	18.775
27	17.20%	17.20%	42.048	18.929
28	17.83%	17.83%	43.605	19.059
29	18.47%	18.47%	45.162	19.165
30	19.11%	19.11%	46.720	19.248
31	19.75%	19.75%	48.277	19.310
32	20.38%	20.38%	49.834	19.353
33	21.02%	21.02%	51.392	19.376

34	21.66%	21.66%	52.949	19.382
35	22.29%	22.29%	54.506	19.371
36	22.93%	22.93%	56.064	19.344
37	23.57%	23.57%	57.621	19.302
38	24.20%	24.20%	59.178	19.246
39	24.84%	24.84%	60.736	19.178
40	25.48%	25.48%	62.293	19.096
41	26.11%	26.11%	63.850	19.004
42	26.75%	26.75%	65.408	18.900
43	27.39%	27.39%	66.965	18.787
44	28.03%	28.03%	68.522	18.664
45	28.66%	28.66%	70.080	18.532
46	29.30%	29.30%	71.637	18.392
47	29.94%	29.94%	73.194	18.244
48	30.57%	30.57%	74.752	18.090
49	31.21%	31.21%	76.309	17.929
50	31.85%	31.85%	77.866	17.762
51	32.48%	32.48%	79.424	17.589
52	33.12%	33.12%	80.981	17.412
53	33.76%	33.76%	82.538	17.230
54	34.39%	34.39%	84.096	17.044
55	35.03%	35.03%	85.653	16.854
56	35.67%	35.67%	87.210	16.660
57	36.31%	36.31%	88.768	16.464
58	36.94%	36.94%	90.325	16.265
59	37.58%	37.58%	91.882	16.063
60	38.22%	38.22%	93.439	15.860
61	38.85%	38.85%	94.997	15.654
62	39.49%	39.49%	96.554	15.448
63	40.13%	40.13%	98.111	15.240
64	40.76%	40.76%	99.669	15.031
65	41.40%	41.40%	101.226	14.821
66	42.04%	42.04%	102.783	14.611
67	42.68%	42.68%	104.341	14.400
68	43.31%	43.31%	105.898	14.189
69	43.95%	43.95%	107.455	13.978
70	44.59%	44.59%	109.013	13.768
71	45.22%	45.22%	110.570	13.558
72	45.86%	45.86%	112.127	13.348
73	46.50%	46.50%	113.685	13.140
74	47.13%	47.13%	115.242	12.932
75	47.77%	47.77%	116.799	12.725
76	48.41%	48.41%	118.357	12.519
77	49.04%	49.04%	119.914	12.314
78	49.68%	49.68%	121.471	12.111
79	50.32%	50.32%	123.029	11.909
80	50.96%	50.96%	124.586	11.708
81	51.59%	51.59%	126.143	11.509
82	52.23%	52.23%	127.701	11.312
83	52.87%	52.87%	129.258	11.116
84	53.50%	53.50%	130.815	10.923
85	54.14%	54.14%	132.373	10.731

86	54.78%	54.78%	133.930	10.541
87	55.41%	55.41%	135.487	10.353
88	56.05%	56.05%	137.045	10.167
89	56.69%	56.69%	138.602	9.983
90	57.32%	57.32%	140.159	9.801
91	57.96%	57.96%	141.717	9.621
92	58.60%	58.60%	143.274	9.444
93	59.24%	59.24%	144.831	9.268
94	59.87%	59.87%	146.389	9.095
95	60.51%	60.51%	147.946	8.924
96	61.15%	61.15%	149.503	8.755
97	61.78%	61.78%	151.061	8.589
98	62.42%	62.42%	152.618	8.425
99	63.06%	63.06%	154.175	8.263
100	63.69%	63.69%	155.732	8.103
101	64.33%	64.33%	157.290	7.946
102	64.97%	64.97%	158.847	7.791
103	65.61%	65.61%	160.404	7.638
104	66.24%	66.24%	161.962	7.488
105	66.88%	66.88%	163.519	7.339
106	67.52%	67.52%	165.076	7.193
107	68.15%	68.15%	166.634	7.050
108	68.79%	68.79%	168.191	6.908
109	69.43%	69.43%	169.748	6.769
110	70.06%	70.06%	171.306	6.632
111	70.70%	70.70%	172.863	6.498
112	71.34%	71.34%	174.420	6.365
113	71.97%	71.97%	175.978	6.235
114	72.61%	72.61%	177.535	6.107
115	73.25%	73.25%	179.092	5.981
116	73.89%	73.89%	180.650	5.858
117	74.52%	74.52%	182.207	5.736
118	75.16%	75.16%	183.764	5.617
119	75.80%	75.80%	185.322	5.499
120	76.43%	76.43%	186.879	5.384
121	77.07%	77.07%	188.436	5.271
122	77.71%	77.71%	189.994	5.159
123	78.34%	78.34%	191.551	5.050
124	78.98%	78.98%	193.108	4.943
125	79.62%	79.62%	194.666	4.838
126	80.25%	80.25%	196.223	4.734
127	80.89%	80.89%	197.780	4.633
128	81.53%	81.53%	199.338	4.533
129	82.17%	82.17%	200.895	4.436
130	82.80%	82.80%	202.452	4.340
131	83.44%	83.44%	204.010	4.246
132	84.08%	84.08%	205.567	4.154
133	84.71%	84.71%	207.124	4.063
134	85.35%	85.35%	208.682	3.975
135	85.99%	85.99%	210.239	3.888
136	86.62%	86.62%	211.796	3.802
137	87.26%	87.26%	213.354	3.719

138	87.90%	87.90%	214.911	3.637
139	88.54%	88.54%	216.468	3.556
140	89.17%	89.17%	218.025	3.478
141	89.81%	89.81%	219.583	3.401
142	90.45%	90.45%	221.140	3.325
143	91.08%	91.08%	222.697	3.251
144	91.72%	91.72%	224.255	3.178
145	92.36%	92.36%	225.812	3.107
146	92.99%	92.99%	227.369	3.037
147	93.63%	93.63%	228.927	2.969
148	94.27%	94.27%	230.484	2.902
149	94.90%	94.90%	232.041	2.837
150	95.54%	95.54%	233.599	2.773
151	96.18%	96.18%	235.156	2.710
152	96.82%	96.82%	236.713	2.648
153	97.45%	97.45%	238.271	2.588
154	98.09%	98.09%	239.828	2.529
155	98.73%	98.73%	241.385	2.471
156	99.36%	99.36%	242.943	2.415
157	100.00%	100.00%	244.500	2.360
Beyond (e)				78.653
Total				1,765.072

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.00%	0.000	0.000
18	0.57%	0.57%	1.555	0.913
19	1.15%	1.15%	3.109	1.773
20	1.72%	1.72%	4.664	2.582
21	2.30%	2.30%	6.218	3.343
22	2.87%	2.87%	7.773	4.057
23	3.45%	3.45%	9.328	4.726
24	4.02%	4.02%	10.882	5.353
25	4.60%	4.60%	12.437	5.940
26	5.17%	5.17%	13.991	6.488
27	5.75%	5.75%	15.546	6.999
28	6.32%	6.32%	17.101	7.474
29	6.90%	6.90%	18.655	7.916
30	7.47%	7.47%	20.210	8.326
31	8.05%	8.05%	21.764	8.705
32	8.62%	8.62%	23.319	9.056
33	9.20%	9.20%	24.874	9.378
34	9.77%	9.77%	26.428	9.674
35	10.34%	10.34%	27.983	9.945
36	10.92%	10.92%	29.537	10.191
37	11.49%	11.49%	31.092	10.415

38	12.07%	12.07%	32.647	10.618
39	12.64%	12.64%	34.201	10.799
40	13.22%	13.22%	35.756	10.961
41	13.79%	13.79%	37.310	11.105
42	14.37%	14.37%	38.865	11.230
43	14.94%	14.94%	40.420	11.339
44	15.52%	15.52%	41.974	11.433
45	16.09%	16.09%	43.529	11.511
46	16.67%	16.67%	45.083	11.575
47	17.24%	17.24%	46.638	11.625
48	17.82%	17.82%	48.193	11.663
49	18.39%	18.39%	49.747	11.688
50	18.97%	18.97%	51.302	11.702
51	19.54%	19.54%	52.856	11.706
52	20.11%	20.11%	54.411	11.699
53	20.69%	20.69%	55.966	11.683
54	21.26%	21.26%	57.520	11.658
55	21.84%	21.84%	59.075	11.624
56	22.41%	22.41%	60.629	11.582
57	22.99%	22.99%	62.184	11.533
58	23.56%	23.56%	63.739	11.477
59	24.14%	24.14%	65.293	11.415
60	24.71%	24.71%	66.848	11.346
61	25.29%	25.29%	68.402	11.272
62	25.86%	25.86%	69.957	11.192
63	26.44%	26.44%	71.511	11.108
64	27.01%	27.01%	73.066	11.019
65	27.59%	27.59%	74.621	10.925
66	28.16%	28.16%	76.175	10.828
67	28.74%	28.74%	77.730	10.727
68	29.31%	29.31%	79.284	10.623
69	29.89%	29.89%	80.839	10.516
70	30.46%	30.46%	82.394	10.406
71	31.03%	31.03%	83.948	10.294
72	31.61%	31.61%	85.503	10.179
73	32.18%	32.18%	87.057	10.062
74	32.76%	32.76%	88.612	9.943
75	33.33%	33.33%	90.167	9.823
76	33.91%	33.91%	91.721	9.702
77	34.48%	34.48%	93.276	9.579
78	35.06%	35.06%	94.830	9.455
79	35.63%	35.63%	96.385	9.330
80	36.21%	36.21%	97.940	9.204
81	36.78%	36.78%	99.494	9.078
82	37.36%	37.36%	101.049	8.951
83	37.93%	37.93%	102.603	8.824
84	38.51%	38.51%	104.158	8.697
85	39.08%	39.08%	105.713	8.570
86	39.66%	39.66%	107.267	8.442
87	40.23%	40.23%	108.822	8.315
88	40.80%	40.80%	110.376	8.188
89	41.38%	41.38%	111.931	8.062

90	41.95%	41.95%	113.486	7.936
91	42.53%	42.53%	115.040	7.810
92	43.10%	43.10%	116.595	7.685
93	43.68%	43.68%	118.149	7.561
94	44.25%	44.25%	119.704	7.437
95	44.83%	44.83%	121.259	7.314
96	45.40%	45.40%	122.813	7.192
97	45.98%	45.98%	124.368	7.071
98	46.55%	46.55%	125.922	6.951
99	47.13%	47.13%	127.477	6.832
100	47.70%	47.70%	129.032	6.714
101	48.28%	48.28%	130.586	6.597
102	48.85%	48.85%	132.141	6.481
103	49.43%	49.43%	133.695	6.366
104	50.00%	50.00%	135.250	6.253
105	50.57%	50.57%	136.805	6.140
106	51.15%	51.15%	138.359	6.029
107	51.72%	51.72%	139.914	5.919
108	52.30%	52.30%	141.468	5.811
109	52.87%	52.87%	143.023	5.704
110	53.45%	53.45%	144.578	5.598
111	54.02%	54.02%	146.132	5.493
112	54.60%	54.60%	147.687	5.390
113	55.17%	55.17%	149.241	5.288
114	55.75%	55.75%	150.796	5.187
115	56.32%	56.32%	152.351	5.088
116	56.90%	56.90%	153.905	4.990
117	57.47%	57.47%	155.460	4.894
118	58.05%	58.05%	157.014	4.799
119	58.62%	58.62%	158.569	4.705
120	59.20%	59.20%	160.124	4.613
121	59.77%	59.77%	161.678	4.522
122	60.34%	60.34%	163.233	4.433
123	60.92%	60.92%	164.787	4.345
124	61.49%	61.49%	166.342	4.258
125	62.07%	62.07%	167.897	4.172
126	62.64%	62.64%	169.451	4.088
127	63.22%	63.22%	171.006	4.006
128	63.79%	63.79%	172.560	3.924
129	64.37%	64.37%	174.115	3.844
130	64.94%	64.94%	175.670	3.766
131	65.52%	65.52%	177.224	3.688
132	66.09%	66.09%	178.779	3.612
133	66.67%	66.67%	180.333	3.538
134	67.24%	67.24%	181.888	3.464
135	67.82%	67.82%	183.443	3.392
136	68.39%	68.39%	184.997	3.321
137	68.97%	68.97%	186.552	3.252
138	69.54%	69.54%	188.106	3.183
139	70.11%	70.11%	189.661	3.116
140	70.69%	70.69%	191.216	3.050
141	71.26%	71.26%	192.770	2.985

142	71.84%	71.84%	194.325	2.922
143	72.41%	72.41%	195.879	2.859
144	72.99%	72.99%	197.434	2.798
145	73.56%	73.56%	198.989	2.738
146	74.14%	74.14%	200.543	2.679
147	74.71%	74.71%	202.098	2.621
148	75.29%	75.29%	203.652	2.564
149	75.86%	75.86%	205.207	2.509
150	76.44%	76.44%	206.761	2.454
151	77.01%	77.01%	208.316	2.401
152	77.59%	77.59%	209.871	2.348
153	78.16%	78.16%	211.425	2.296
154	78.74%	78.74%	212.980	2.246
155	79.31%	79.31%	214.534	2.196
156	79.89%	79.89%	216.089	2.148
157	80.46%	80.46%	217.644	2.100
158	81.03%	81.03%	219.198	2.054
159	81.61%	81.61%	220.753	2.008
160	82.18%	82.18%	222.307	1.963
161	82.76%	82.76%	223.862	1.919
162	83.33%	83.33%	225.417	1.877
163	83.91%	83.91%	226.971	1.834
164	84.48%	84.48%	228.526	1.793
165	85.06%	85.06%	230.080	1.753
166	85.63%	85.63%	231.635	1.713
167	86.21%	86.21%	233.190	1.675
168	86.78%	86.78%	234.744	1.637
169	87.36%	87.36%	236.299	1.599
170	87.93%	87.93%	237.853	1.563
171	88.51%	88.51%	239.408	1.527
172	89.08%	89.08%	240.963	1.493
173	89.66%	89.66%	242.517	1.458
174	90.23%	90.23%	244.072	1.425
175	90.80%	90.80%	245.626	1.392
176	91.38%	91.38%	247.181	1.360
177	91.95%	91.95%	248.736	1.329
178	92.53%	92.53%	250.290	1.298
179	93.10%	93.10%	251.845	1.268
180	93.68%	93.68%	253.399	1.239
181	94.25%	94.25%	254.954	1.210
182	94.83%	94.83%	256.509	1.182
183	95.40%	95.40%	258.063	1.155
184	95.98%	95.98%	259.618	1.128
185	96.55%	96.55%	261.172	1.102
186	97.13%	97.13%	262.727	1.076
187	97.70%	97.70%	264.282	1.051
188	98.28%	98.28%	265.836	1.026
189	98.85%	98.85%	267.391	1.002
190	99.43%	99.43%	268.945	0.979
191	100.00%	100.00%	270.500	0.956
Beyond (f)				31.852
Total				1,070.130

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0.000	0.000
1	0.57%	0.57%	1.555	1.509
2	1.15%	1.15%	3.109	2.931
3	1.72%	1.72%	4.664	4.268
4	2.30%	2.30%	6.218	5.525
5	2.87%	2.87%	7.773	6.705
6	3.45%	3.45%	9.328	7.812
7	4.02%	4.02%	10.882	8.848
8	4.60%	4.60%	12.437	9.818
9	5.17%	5.17%	13.991	10.723
10	5.75%	5.75%	15.546	11.568
11	6.32%	6.32%	17.101	12.354
12	6.90%	6.90%	18.655	13.084
13	7.47%	7.47%	20.210	13.762
14	8.05%	8.05%	21.764	14.389
15	8.62%	8.62%	23.319	14.968
16	9.20%	9.20%	24.874	15.500
17	9.77%	9.77%	26.428	15.989
18	10.34%	10.34%	27.983	16.437
19	10.92%	10.92%	29.537	16.845
20	11.49%	11.49%	31.092	17.215
21	12.07%	12.07%	32.647	17.549
22	12.64%	12.64%	34.201	17.849
23	13.22%	13.22%	35.756	18.117
24	13.79%	13.79%	37.310	18.354
25	14.37%	14.37%	38.865	18.562
26	14.94%	14.94%	40.420	18.742
27	15.52%	15.52%	41.974	18.896
28	16.09%	16.09%	43.529	19.025
29	16.67%	16.67%	45.083	19.131
30	17.24%	17.24%	46.638	19.214
31	17.82%	17.82%	48.193	19.276
32	18.39%	18.39%	49.747	19.319
33	18.97%	18.97%	51.302	19.342
34	19.54%	19.54%	52.856	19.348
35	20.11%	20.11%	54.411	19.337
36	20.69%	20.69%	55.966	19.310
37	21.26%	21.26%	57.520	19.268
38	21.84%	21.84%	59.075	19.213
39	22.41%	22.41%	60.629	19.144
40	22.99%	22.99%	62.184	19.063
41	23.56%	23.56%	63.739	18.970
42	24.14%	24.14%	65.293	18.867

43	24.71%	24.71%	66.848	18.754
44	25.29%	25.29%	68.402	18.631
45	25.86%	25.86%	69.957	18.499
46	26.44%	26.44%	71.511	18.360
47	27.01%	27.01%	73.066	18.212
48	27.59%	27.59%	74.621	18.058
49	28.16%	28.16%	76.175	17.897
50	28.74%	28.74%	77.730	17.731
51	29.31%	29.31%	79.284	17.559
52	29.89%	29.89%	80.839	17.381
53	30.46%	30.46%	82.394	17.200
54	31.03%	31.03%	83.948	17.014
55	31.61%	31.61%	85.503	16.824
56	32.18%	32.18%	87.057	16.631
57	32.76%	32.76%	88.612	16.435
58	33.33%	33.33%	90.167	16.236
59	33.91%	33.91%	91.721	16.035
60	34.48%	34.48%	93.276	15.832
61	35.06%	35.06%	94.830	15.627
62	35.63%	35.63%	96.385	15.421
63	36.21%	36.21%	97.940	15.213
64	36.78%	36.78%	99.494	15.004
65	37.36%	37.36%	101.049	14.795
66	37.93%	37.93%	102.603	14.585
67	38.51%	38.51%	104.158	14.375
68	39.08%	39.08%	105.713	14.164
69	39.66%	39.66%	107.267	13.954
70	40.23%	40.23%	108.822	13.744
71	40.80%	40.80%	110.376	13.534
72	41.38%	41.38%	111.931	13.325
73	41.95%	41.95%	113.486	13.117
74	42.53%	42.53%	115.040	12.909
75	43.10%	43.10%	116.595	12.702
76	43.68%	43.68%	118.149	12.497
77	44.25%	44.25%	119.704	12.293
78	44.83%	44.83%	121.259	12.090
79	45.40%	45.40%	122.813	11.888
80	45.98%	45.98%	124.368	11.688
81	46.55%	46.55%	125.922	11.489
82	47.13%	47.13%	127.477	11.292
83	47.70%	47.70%	129.032	11.097
84	48.28%	48.28%	130.586	10.904
85	48.85%	48.85%	132.141	10.712
86	49.43%	49.43%	133.695	10.522
87	50.00%	50.00%	135.250	10.335
88	50.57%	50.57%	136.805	10.149
89	51.15%	51.15%	138.359	9.965
90	51.72%	51.72%	139.914	9.784
91	52.30%	52.30%	141.468	9.604
92	52.87%	52.87%	143.023	9.427
93	53.45%	53.45%	144.578	9.252
94	54.02%	54.02%	146.132	9.079

95	54.60%	54.60%	147.687	8.909
96	55.17%	55.17%	149.241	8.740
97	55.75%	55.75%	150.796	8.574
98	56.32%	56.32%	152.351	8.410
99	56.90%	56.90%	153.905	8.248
100	57.47%	57.47%	155.460	8.089
101	58.05%	58.05%	157.014	7.932
102	58.62%	58.62%	158.569	7.777
103	59.20%	59.20%	160.124	7.625
104	59.77%	59.77%	161.678	7.474
105	60.34%	60.34%	163.233	7.327
106	60.92%	60.92%	164.787	7.181
107	61.49%	61.49%	166.342	7.038
108	62.07%	62.07%	167.897	6.896
109	62.64%	62.64%	169.451	6.758
110	63.22%	63.22%	171.006	6.621
111	63.79%	63.79%	172.560	6.486
112	64.37%	64.37%	174.115	6.354
113	64.94%	64.94%	175.670	6.224
114	65.52%	65.52%	177.224	6.096
115	66.09%	66.09%	178.779	5.971
116	66.67%	66.67%	180.333	5.847
117	67.24%	67.24%	181.888	5.726
118	67.82%	67.82%	183.443	5.607
119	68.39%	68.39%	184.997	5.490
120	68.97%	68.97%	186.552	5.374
121	69.54%	69.54%	188.106	5.261
122	70.11%	70.11%	189.661	5.150
123	70.69%	70.69%	191.216	5.041
124	71.26%	71.26%	192.770	4.934
125	71.84%	71.84%	194.325	4.829
126	72.41%	72.41%	195.879	4.726
127	72.99%	72.99%	197.434	4.625
128	73.56%	73.56%	198.989	4.525
129	74.14%	74.14%	200.543	4.428
130	74.71%	74.71%	202.098	4.332
131	75.29%	75.29%	203.652	4.239
132	75.86%	75.86%	205.207	4.146
133	76.44%	76.44%	206.761	4.056
134	77.01%	77.01%	208.316	3.968
135	77.59%	77.59%	209.871	3.881
136	78.16%	78.16%	211.425	3.796
137	78.74%	78.74%	212.980	3.712
138	79.31%	79.31%	214.534	3.630
139	79.89%	79.89%	216.089	3.550
140	80.46%	80.46%	217.644	3.472
141	81.03%	81.03%	219.198	3.395
142	81.61%	81.61%	220.753	3.319
143	82.18%	82.18%	222.307	3.245
144	82.76%	82.76%	223.862	3.173
145	83.33%	83.33%	225.417	3.102
146	83.91%	83.91%	226.971	3.032

147	84.48%	84.48%	228.526	2.964
148	85.06%	85.06%	230.080	2.897
149	85.63%	85.63%	231.635	2.832
150	86.21%	86.21%	233.190	2.768
151	86.78%	86.78%	234.744	2.705
152	87.36%	87.36%	236.299	2.644
153	87.93%	87.93%	237.853	2.584
154	88.51%	88.51%	239.408	2.525
155	89.08%	89.08%	240.963	2.467
156	89.66%	89.66%	242.517	2.411
157	90.23%	90.23%	244.072	2.355
158	90.80%	90.80%	245.626	2.301
159	91.38%	91.38%	247.181	2.249
160	91.95%	91.95%	248.736	2.197
161	92.53%	92.53%	250.290	2.146
162	93.10%	93.10%	251.845	2.097
163	93.68%	93.68%	253.399	2.048
164	94.25%	94.25%	254.954	2.001
165	94.83%	94.83%	256.509	1.954
166	95.40%	95.40%	258.063	1.909
167	95.98%	95.98%	259.618	1.864
168	96.55%	96.55%	261.172	1.821
169	97.13%	97.13%	262.727	1.778
170	97.70%	97.70%	264.282	1.737
171	98.28%	98.28%	265.836	1.696
172	98.85%	98.85%	267.391	1.656
173	99.43%	99.43%	268.945	1.617
174	100.00%	100.00%	270.500	1.579
Beyond (g)				52.646
Total				1,768.763

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%

20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	6,320
Lake Ashtabula - Jump Dispersal (acres):	7,160
Upper Sheyenne River - Progressive Dispersal (river-miles):	80.1
Lower Sheyenne River - Progressive Dispersal (river-miles):	48.6
Lower Sheyenne River - Jump Dispersal (river-miles):	80.3

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 158 into perpetuity

(f) From year 192 into perpetuity

(g) From year 175 into perpetuity

(h) From year 26 into perpetuity

Appendix 2G. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Fast Invasion - Very Low Risk (One Organism)

Probability of successful invasion:	1.00E-09
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.000000000	0.000000000
1	100.00%	0.00000010000%	0.000005234	0.000005082
Beyond (c)				0.000169385
Total				0.000174467

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	0.00000010000%	0.000005234	0.000005234
Beyond (d)				0.000174467
Total				0.000179701

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.000000000	0.000000000
1	6.67%	0.00000000667%	0.000000016	0.000000016
2	13.33%	0.00000001333%	0.000000033	0.000000031
3	20.00%	0.00000002000%	0.000000049	0.000000045
4	26.67%	0.00000002667%	0.000000065	0.000000058
5	33.33%	0.00000003333%	0.000000082	0.000000070

6	40.00%	0.00000004000%	0.000000098	0.000000082
7	46.67%	0.00000004667%	0.000000114	0.000000093
8	53.33%	0.00000005333%	0.000000130	0.000000103
9	60.00%	0.00000006000%	0.000000147	0.000000112
10	66.67%	0.00000006667%	0.000000163	0.000000121
11	73.33%	0.00000007333%	0.000000179	0.000000130
12	80.00%	0.00000008000%	0.000000196	0.000000137
13	86.67%	0.00000008667%	0.000000212	0.000000144
14	93.33%	0.00000009333%	0.000000228	0.000000151
15	100.00%	0.00000010000%	0.000000245	0.000000157
Beyond (e)				0.000005231
Total				0.000006681

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.00000000000%	0.000000000	0.000000000
2	5.88%	0.00000000588%	0.000000016	0.000000015
3	11.76%	0.00000001176%	0.000000032	0.000000029
4	17.65%	0.00000001765%	0.000000048	0.000000042
5	23.53%	0.00000002353%	0.000000064	0.000000055
6	29.41%	0.00000002941%	0.000000080	0.000000067
7	35.29%	0.00000003529%	0.000000095	0.000000078
8	41.18%	0.00000004118%	0.000000111	0.000000088
9	47.06%	0.00000004706%	0.000000127	0.000000098
10	52.94%	0.00000005294%	0.000000143	0.000000107
11	58.82%	0.00000005882%	0.000000159	0.000000115
12	64.71%	0.00000006471%	0.000000175	0.000000123
13	70.59%	0.00000007059%	0.000000191	0.000000130
14	76.47%	0.00000007647%	0.000000207	0.000000137
15	82.35%	0.00000008235%	0.000000223	0.000000143
16	88.24%	0.00000008824%	0.000000239	0.000000149
17	94.12%	0.00000009412%	0.000000255	0.000000154
18	100.00%	0.00000010000%	0.000000271	0.000000159
Beyond (f)				0.000005296
Total				0.000006983

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.000000000	0.000000000
1	5.88%	0.00000000588%	0.000000016	0.000000015

2	11.76%	0.00000001176%	0.000000032	0.000000030
3	17.65%	0.00000001765%	0.000000048	0.000000044
4	23.53%	0.00000002353%	0.000000064	0.000000057
5	29.41%	0.00000002941%	0.000000080	0.000000069
6	35.29%	0.00000003529%	0.000000095	0.000000080
7	41.18%	0.00000004118%	0.000000111	0.000000091
8	47.06%	0.00000004706%	0.000000127	0.000000100
9	52.94%	0.00000005294%	0.000000143	0.000000110
10	58.82%	0.00000005882%	0.000000159	0.000000118
11	64.71%	0.00000006471%	0.000000175	0.000000126
12	70.59%	0.00000007059%	0.000000191	0.000000134
13	76.47%	0.00000007647%	0.000000207	0.000000141
14	82.35%	0.00000008235%	0.000000223	0.000000147
15	88.24%	0.00000008824%	0.000000239	0.000000153
16	94.12%	0.00000009412%	0.000000255	0.000000159
17	100.00%	0.00000010000%	0.000000271	0.000000164
Beyond (g)				0.000005455
Total				0.000007193

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	0.00000792
Lake Ashtabula - Jump Dispersal (acres):	0.00000816
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.000000303
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.000000317
Lower Sheyenne River - Jump Dispersal (river-miles):	0.000000326

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 16 into perpetuity

(f) From year 19 into perpetuity

(g) From year 18 into perpetuity

(h) From year 26 into perpetuity

Appendix 2H. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Fast Invasion - Low Risk (One Organism)

Probability of successful invasion:	1.00E-06
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.000000	0.000000
1	100.00%	0.00010000%	0.005234	0.005082
Beyond (c)				0.169385
Total				0.174467

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	0.00010000%	0.005234	0.005234
Beyond (d)				0.174467
Total				0.179701

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.000000	0.000000
1	6.67%	0.00000667%	0.000016	0.000016
2	13.33%	0.00001333%	0.000033	0.000031
3	20.00%	0.00002000%	0.000049	0.000045
4	26.67%	0.00002667%	0.000065	0.000058
5	33.33%	0.00003333%	0.000082	0.000070

6	40.00%	0.00004000%	0.000098	0.000082
7	46.67%	0.00004667%	0.000114	0.000093
8	53.33%	0.00005333%	0.000130	0.000103
9	60.00%	0.00006000%	0.000147	0.000112
10	66.67%	0.00006667%	0.000163	0.000121
11	73.33%	0.00007333%	0.000179	0.000130
12	80.00%	0.00008000%	0.000196	0.000137
13	86.67%	0.00008667%	0.000212	0.000144
14	93.33%	0.00009333%	0.000228	0.000151
15	100.00%	0.00010000%	0.000245	0.000157
Beyond (e)				0.005231
Total				0.006681

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.00000000%	0.000000	0.000000
2	5.88%	0.00000588%	0.000016	0.000015
3	11.76%	0.00001176%	0.000032	0.000029
4	17.65%	0.00001765%	0.000048	0.000042
5	23.53%	0.00002353%	0.000064	0.000055
6	29.41%	0.00002941%	0.000080	0.000067
7	35.29%	0.00003529%	0.000095	0.000078
8	41.18%	0.00004118%	0.000111	0.000088
9	47.06%	0.00004706%	0.000127	0.000098
10	52.94%	0.00005294%	0.000143	0.000107
11	58.82%	0.00005882%	0.000159	0.000115
12	64.71%	0.00006471%	0.000175	0.000123
13	70.59%	0.00007059%	0.000191	0.000130
14	76.47%	0.00007647%	0.000207	0.000137
15	82.35%	0.00008235%	0.000223	0.000143
16	88.24%	0.00008824%	0.000239	0.000149
17	94.12%	0.00009412%	0.000255	0.000154
18	100.00%	0.00010000%	0.000271	0.000159
Beyond (f)				0.005296
Total				0.006983

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.000000	0.000000
1	5.88%	0.00000588%	0.000016	0.000015

2	11.76%	0.00001176%	0.000032	0.000030
3	17.65%	0.00001765%	0.000048	0.000044
4	23.53%	0.00002353%	0.000064	0.000057
5	29.41%	0.00002941%	0.000080	0.000069
6	35.29%	0.00003529%	0.000095	0.000080
7	41.18%	0.00004118%	0.000111	0.000091
8	47.06%	0.00004706%	0.000127	0.000100
9	52.94%	0.00005294%	0.000143	0.000110
10	58.82%	0.00005882%	0.000159	0.000118
11	64.71%	0.00006471%	0.000175	0.000126
12	70.59%	0.00007059%	0.000191	0.000134
13	76.47%	0.00007647%	0.000207	0.000141
14	82.35%	0.00008235%	0.000223	0.000147
15	88.24%	0.00008824%	0.000239	0.000153
16	94.12%	0.00009412%	0.000255	0.000159
17	100.00%	0.00010000%	0.000271	0.000164
Beyond (g)				0.005455
Total				0.007193

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	0.00792
Lake Ashtabula - Jump Dispersal (acres):	0.00816
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.000303
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.000317
Lower Sheyenne River - Jump Dispersal (river-miles):	0.000326

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 16 into perpetuity

(f) From year 19 into perpetuity

(g) From year 18 into perpetuity

(h) From year 26 into perpetuity

Appendix 2I. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Fast Invasion - Moderate Risk (One Organism)

Probability of successful invasion:	1.00E-03
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.000	0.000
1	100.00%	0.10000%	5.234	5.082
Beyond (c)				169.385
Total				174.467

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	0.10000%	5.234	5.234
Beyond (d)				174.467
Total				179.701

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.000	0.000
1	6.67%	0.00667%	0.016	0.016
2	13.33%	0.01333%	0.033	0.031
3	20.00%	0.02000%	0.049	0.045
4	26.67%	0.02667%	0.065	0.058
5	33.33%	0.03333%	0.082	0.070

6	40.00%	0.04000%	0.098	0.082
7	46.67%	0.04667%	0.114	0.093
8	53.33%	0.05333%	0.130	0.103
9	60.00%	0.06000%	0.147	0.112
10	66.67%	0.06667%	0.163	0.121
11	73.33%	0.07333%	0.179	0.130
12	80.00%	0.08000%	0.196	0.137
13	86.67%	0.08667%	0.212	0.144
14	93.33%	0.09333%	0.228	0.151
15	100.00%	0.10000%	0.245	0.157
Beyond (e)				5.231
Total				6.681

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.00000%	0.000	0.000
2	5.88%	0.00588%	0.016	0.015
3	11.76%	0.01176%	0.032	0.029
4	17.65%	0.01765%	0.048	0.042
5	23.53%	0.02353%	0.064	0.055
6	29.41%	0.02941%	0.080	0.067
7	35.29%	0.03529%	0.095	0.078
8	41.18%	0.04118%	0.111	0.088
9	47.06%	0.04706%	0.127	0.098
10	52.94%	0.05294%	0.143	0.107
11	58.82%	0.05882%	0.159	0.115
12	64.71%	0.06471%	0.175	0.123
13	70.59%	0.07059%	0.191	0.130
14	76.47%	0.07647%	0.207	0.137
15	82.35%	0.08235%	0.223	0.143
16	88.24%	0.08824%	0.239	0.149
17	94.12%	0.09412%	0.255	0.154
18	100.00%	0.10000%	0.271	0.159
Beyond (f)				5.296
Total				6.983

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.000	0.000
1	5.88%	0.00588%	0.016	0.015

2	11.76%	0.01176%	0.032	0.030
3	17.65%	0.01765%	0.048	0.044
4	23.53%	0.02353%	0.064	0.057
5	29.41%	0.02941%	0.080	0.069
6	35.29%	0.03529%	0.095	0.080
7	41.18%	0.04118%	0.111	0.091
8	47.06%	0.04706%	0.127	0.100
9	52.94%	0.05294%	0.143	0.110
10	58.82%	0.05882%	0.159	0.118
11	64.71%	0.06471%	0.175	0.126
12	70.59%	0.07059%	0.191	0.134
13	76.47%	0.07647%	0.207	0.141
14	82.35%	0.08235%	0.223	0.147
15	88.24%	0.08824%	0.239	0.153
16	94.12%	0.09412%	0.255	0.159
17	100.00%	0.10000%	0.271	0.164
Beyond (g)				5.455
Total				7.193

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	7.92
Lake Ashtabula - Jump Dispersal (acres):	8.16
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.303
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.317
Lower Sheyenne River - Jump Dispersal (river-miles):	0.326

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 16 into perpetuity

(f) From year 19 into perpetuity

(g) From year 18 into perpetuity

(h) From year 26 into perpetuity

Appendix 2J. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Fast Invasion - High Risk (One Organism)

Probability of successful invasion:	1.00E-02
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.00	0.00
1	100.00%	1.0000%	52.34	50.82
Beyond (c)				1,693.85
Total				1,744.67

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	1.0000%	52.34	52.34
Beyond (d)				1,744.67
Total				1,797.01

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.00	0.00
1	6.67%	0.0667%	0.16	0.16
2	13.33%	0.1333%	0.33	0.31
3	20.00%	0.2000%	0.49	0.45
4	26.67%	0.2667%	0.65	0.58
5	33.33%	0.3333%	0.82	0.70

6	40.00%	0.4000%	0.98	0.82
7	46.67%	0.4667%	1.14	0.93
8	53.33%	0.5333%	1.30	1.03
9	60.00%	0.6000%	1.47	1.12
10	66.67%	0.6667%	1.63	1.21
11	73.33%	0.7333%	1.79	1.30
12	80.00%	0.8000%	1.96	1.37
13	86.67%	0.8667%	2.12	1.44
14	93.33%	0.9333%	2.28	1.51
15	100.00%	1.0000%	2.45	1.57
Beyond (e)				52.31
Total				66.81

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.0000%	0.00	0.00
2	5.88%	0.0588%	0.16	0.15
3	11.76%	0.1176%	0.32	0.29
4	17.65%	0.1765%	0.48	0.42
5	23.53%	0.2353%	0.64	0.55
6	29.41%	0.2941%	0.80	0.67
7	35.29%	0.3529%	0.95	0.78
8	41.18%	0.4118%	1.11	0.88
9	47.06%	0.4706%	1.27	0.98
10	52.94%	0.5294%	1.43	1.07
11	58.82%	0.5882%	1.59	1.15
12	64.71%	0.6471%	1.75	1.23
13	70.59%	0.7059%	1.91	1.30
14	76.47%	0.7647%	2.07	1.37
15	82.35%	0.8235%	2.23	1.43
16	88.24%	0.8824%	2.39	1.49
17	94.12%	0.9412%	2.55	1.54
18	100.00%	1.0000%	2.71	1.59
Beyond (f)				52.96
Total				69.83

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.00	0.00
1	5.88%	0.0588%	0.16	0.15

2	11.76%	0.1176%	0.32	0.30
3	17.65%	0.1765%	0.48	0.44
4	23.53%	0.2353%	0.64	0.57
5	29.41%	0.2941%	0.80	0.69
6	35.29%	0.3529%	0.95	0.80
7	41.18%	0.4118%	1.11	0.91
8	47.06%	0.4706%	1.27	1.00
9	52.94%	0.5294%	1.43	1.10
10	58.82%	0.5882%	1.59	1.18
11	64.71%	0.6471%	1.75	1.26
12	70.59%	0.7059%	1.91	1.34
13	76.47%	0.7647%	2.07	1.41
14	82.35%	0.8235%	2.23	1.47
15	88.24%	0.8824%	2.39	1.53
16	94.12%	0.9412%	2.55	1.59
17	100.00%	1.0000%	2.71	1.64
Beyond (g)				54.55
Total				71.93

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	79.2
Lake Ashtabula - Jump Dispersal (acres):	81.6
Upper Sheyenne River - Progressive Dispersal (river-miles):	3.03
Lower Sheyenne River - Progressive Dispersal (river-miles):	3.17
Lower Sheyenne River - Jump Dispersal (river-miles):	3.26

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 16 into perpetuity

(f) From year 19 into perpetuity

(g) From year 18 into perpetuity

(h) From year 26 into perpetuity

Appendix 2K. Habitat Equivalency Analysis of Risk Consequences: GDU Import to Sheyenne River, Fast Invasion - Very High Risk (One Organism)

Probability of successful invasion:	1.00E+00
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0	0
1	100.00%	100.00%	5,234	5,082
Beyond (c)				169,385
Total				174,467

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	100.00%	5,234	5,234
Beyond (d)				174,467
Total				179,701

Section 1.3 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0	0
1	6.67%	6.67%	16	16
2	13.33%	13.33%	33	31
3	20.00%	20.00%	49	45
4	26.67%	26.67%	65	58
5	33.33%	33.33%	82	70

6	40.00%	40.00%	98	82
7	46.67%	46.67%	114	93
8	53.33%	53.33%	130	103
9	60.00%	60.00%	147	112
10	66.67%	66.67%	163	121
11	73.33%	73.33%	179	130
12	80.00%	80.00%	196	137
13	86.67%	86.67%	212	144
14	93.33%	93.33%	228	151
15	100.00%	100.00%	245	157
Beyond (e)				5,231
Total				6,681

Section 1.4 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.00%	0	0
2	5.88%	5.88%	16	15
3	11.76%	11.76%	32	29
4	17.65%	17.65%	48	42
5	23.53%	23.53%	64	55
6	29.41%	29.41%	80	67
7	35.29%	35.29%	95	78
8	41.18%	41.18%	111	88
9	47.06%	47.06%	127	98
10	52.94%	52.94%	143	107
11	58.82%	58.82%	159	115
12	64.71%	64.71%	175	123
13	70.59%	70.59%	191	130
14	76.47%	76.47%	207	137
15	82.35%	82.35%	223	143
16	88.24%	88.24%	239	149
17	94.12%	94.12%	255	154
18	100.00%	100.00%	271	159
Beyond (f)				5,296
Total				6,983

Section 1.5 Lower Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0	0
1	5.88%	5.88%	16	15

2	11.76%	11.76%	32	30
3	17.65%	17.65%	48	44
4	23.53%	23.53%	64	57
5	29.41%	29.41%	80	69
6	35.29%	35.29%	95	80
7	41.18%	41.18%	111	91
8	47.06%	47.06%	127	100
9	52.94%	52.94%	143	110
10	58.82%	58.82%	159	118
11	64.71%	64.71%	175	126
12	70.59%	70.59%	191	134
13	76.47%	76.47%	207	141
14	82.35%	82.35%	223	147
15	88.24%	88.24%	239	153
16	94.12%	94.12%	255	159
17	100.00%	100.00%	271	164
Beyond (g)				5,455
Total				7,193

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	7,920
Lake Ashtabula - Jump Dispersal (acres):	8,160
Upper Sheyenne River - Progressive Dispersal (river-miles):	303
Lower Sheyenne River - Progressive Dispersal (river-miles):	317
Lower Sheyenne River - Jump Dispersal (river-miles):	326

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 16 into perpetuity

(f) From year 19 into perpetuity

(g) From year 18 into perpetuity

(h) From year 26 into perpetuity

Appendix 3A. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Summary of Results

Section 1 Offsetting Restoration for One Organism

Section 1.1 Lake Ashtabula - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (Acres)	Fast Invasion (Acres)
Very Low	1.00E-09	87.0%	0.00000632	0.00000792
Low	1.00E-06	7.6%	0.00632	0.00792
Moderate	1.00E-03	3.7%	6.32	7.92
High	1.00E-02	1.7%	63.2	79.2
Very High	1.00E+00	0.0%	6,320	7,920
Weighted Average (a)			1.31	1.64

Section 1.2 Lake Ashtabula - Jump Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (Acres)	Fast Invasion (Acres)
Very Low	1.00E-09	87.0%	0.00000716	0.00000816
Low	1.00E-06	7.6%	0.00716	0.00816
Moderate	1.00E-03	3.7%	7.16	8.16
High	1.00E-02	1.7%	71.6	81.6
Very High	1.00E+00	0.0%	7,160	8,160
Weighted Average (a)			1.48	1.69

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (River-Miles)	Fast Invasion (River-Miles)
Very Low	1.00E-09	87.0%	0.0000000803	0.000000326
Low	1.00E-06	7.6%	0.0000803	0.000326
Moderate	1.00E-03	3.7%	0.0803	0.326
High	1.00E-02	1.7%	0.803	3.26
Very High	1.00E+00	0.0%	80.3	326
Weighted Average (a)			0.02	0.07

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (River-Miles)	Fast Invasion (River-Miles)
Very Low	1.00E-09	87.0%	0.0000000485	0.000000294
Low	1.00E-06	7.6%	0.0000485	0.000294
Moderate	1.00E-03	3.7%	0.0485	0.294
High	1.00E-02	1.7%	0.485	2.94
Very High	1.00E+00	0.0%	48.5	294
Weighted Average (a)			0.01	0.06

Section 1.5 Upper Sheyenne River - Jump Dispersal

Risk Category	Probability of Successful Invasion	Percent Outcomes	<---Offsetting Restoration for One Organism---> Slow Invasion (River-Miles)	Fast Invasion (River-Miles)
Very Low	1.00E-09	87.0%	0.0000000801	0.000000303
Low	1.00E-06	7.6%	0.0000801	0.000303
Moderate	1.00E-03	3.7%	0.0801	0.303
High	1.00E-02	1.7%	0.801	3.03
Very High	1.00E+00	0.0%	80.1	303
Weighted Average (a)			0.02	0.06

Section 2 Offsetting Restoration for 31 Biota

Section 2.1 Slow Invasion

Dispersal Scenario for the Upper Sheyenne River and Lake Ashtabula	<----Offsetting Restoration for 31 Biota (b)----> Sheyenne River (River-Miles)	Lake Ashtabula (Acres)
0 Jump - 31 Progressive	0.9	40.6
1 Jump - 30 Progressive	0.9	40.8
10 Jump - 21 Progressive	1.0	42.3

Section 2.2 Fast Invasion

Dispersal Scenario for the Upper Sheyenne River and Lake Ashtabula	<----Offsetting Restoration for 31 Biota (b)----> Sheyenne River (River-Miles)	Lake Ashtabula (Acres)
0 Jump - 31 Progressive	4.0	50.8
1 Jump - 30 Progressive	4.0	50.9
10 Jump - 21 Progressive	4.0	51.3

Section 3 Notes

(a) Weighted by the percent outcomes of respective risk categories

(b) Multiples of the weighted averages of the respective offsetting restoration levels for one organism, combined according to the dispersal scenarios for the Upper Sheyenne River and Lake Ashtabula

Appendix 3B. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Slow Invasion - Very Low Risk (One Organism)

Probability of successful invasion:	1.00E-09
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.0000000000	0.0000000000
1	5.88%	0.00000000588%	0.0000003079	0.0000002989
2	11.76%	0.00000001176%	0.0000006158	0.0000005804
3	17.65%	0.00000001765%	0.0000009236	0.0000008453
4	23.53%	0.00000002353%	0.0000012315	0.0000010942
5	29.41%	0.00000002941%	0.0000015394	0.0000013279
6	35.29%	0.00000003529%	0.0000018473	0.0000015471
7	41.18%	0.00000004118%	0.0000021552	0.0000017524
8	47.06%	0.00000004706%	0.0000024631	0.0000019444
9	52.94%	0.00000005294%	0.0000027709	0.0000021237
10	58.82%	0.00000005882%	0.0000030788	0.0000022909
11	64.71%	0.00000006471%	0.0000033867	0.0000024466
12	70.59%	0.00000007059%	0.0000036946	0.0000025913
13	76.47%	0.00000007647%	0.0000040025	0.0000027255
14	82.35%	0.00000008235%	0.0000043104	0.0000028497
15	88.24%	0.00000008824%	0.0000046182	0.0000029643
16	94.12%	0.00000009412%	0.0000049261	0.0000030698
17	100.00%	0.00000010000%	0.0000052340	0.0000031667
Beyond (c)				0.0001055552
Total				0.0001391741

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.0000000000	0.0000000000
1	12.50%	0.00000001250%	0.0000006543	0.0000006352

2	25.00%	0.00000002500%	0.0000013085	0.0000012334
3	37.50%	0.00000003750%	0.0000019628	0.0000017962
4	50.00%	0.00000005000%	0.0000026170	0.0000023252
5	62.50%	0.00000006250%	0.0000032713	0.0000028218
6	75.00%	0.00000007500%	0.0000039255	0.0000032875
7	87.50%	0.00000008750%	0.0000045798	0.0000037238
8	100.00%	0.00000010000%	0.0000052340	0.0000041318
Beyond (d)				0.0001377256
Total				0.0001576804

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.0000000000	0.0000000000
1	0.57%	0.00000000057%	0.0000000016	0.0000000015
2	1.15%	0.00000000115%	0.0000000031	0.0000000029
3	1.72%	0.00000000172%	0.0000000047	0.0000000043
4	2.30%	0.00000000230%	0.0000000062	0.0000000055
5	2.87%	0.00000000287%	0.0000000078	0.0000000067
6	3.45%	0.00000000345%	0.0000000093	0.0000000078
7	4.02%	0.00000000402%	0.0000000109	0.0000000088
8	4.60%	0.00000000460%	0.0000000124	0.0000000098
9	5.17%	0.00000000517%	0.0000000140	0.0000000107
10	5.75%	0.00000000575%	0.0000000155	0.0000000116
11	6.32%	0.00000000632%	0.0000000171	0.0000000124
12	6.90%	0.00000000690%	0.0000000187	0.0000000131
13	7.47%	0.00000000747%	0.0000000202	0.0000000138
14	8.05%	0.00000000805%	0.0000000218	0.0000000144
15	8.62%	0.00000000862%	0.0000000233	0.0000000150
16	9.20%	0.00000000920%	0.0000000249	0.0000000155
17	9.77%	0.00000000977%	0.0000000264	0.0000000160
18	10.34%	0.00000001034%	0.0000000280	0.0000000164
19	10.92%	0.00000001092%	0.0000000295	0.0000000168
20	11.49%	0.00000001149%	0.0000000311	0.0000000172
21	12.07%	0.00000001207%	0.0000000326	0.0000000175
22	12.64%	0.00000001264%	0.0000000342	0.0000000178
23	13.22%	0.00000001322%	0.0000000358	0.0000000181
24	13.79%	0.00000001379%	0.0000000373	0.0000000184
25	14.37%	0.00000001437%	0.0000000389	0.0000000186
26	14.94%	0.00000001494%	0.0000000404	0.0000000187
27	15.52%	0.00000001552%	0.0000000420	0.0000000189
28	16.09%	0.00000001609%	0.0000000435	0.0000000190
29	16.67%	0.00000001667%	0.0000000451	0.0000000191
30	17.24%	0.00000001724%	0.0000000466	0.0000000192
31	17.82%	0.00000001782%	0.0000000482	0.0000000193
32	18.39%	0.00000001839%	0.0000000497	0.0000000193
33	18.97%	0.00000001897%	0.0000000513	0.0000000193

34	19.54%	0.00000001954%	0.0000000529	0.0000000193
35	20.11%	0.00000002011%	0.0000000544	0.0000000193
36	20.69%	0.00000002069%	0.0000000560	0.0000000193
37	21.26%	0.00000002126%	0.0000000575	0.0000000193
38	21.84%	0.00000002184%	0.0000000591	0.0000000192
39	22.41%	0.00000002241%	0.0000000606	0.0000000191
40	22.99%	0.00000002299%	0.0000000622	0.0000000191
41	23.56%	0.00000002356%	0.0000000637	0.0000000190
42	24.14%	0.00000002414%	0.0000000653	0.0000000189
43	24.71%	0.00000002471%	0.0000000668	0.0000000188
44	25.29%	0.00000002529%	0.0000000684	0.0000000186
45	25.86%	0.00000002586%	0.0000000700	0.0000000185
46	26.44%	0.00000002644%	0.0000000715	0.0000000184
47	27.01%	0.00000002701%	0.0000000731	0.0000000182
48	27.59%	0.00000002759%	0.0000000746	0.0000000181
49	28.16%	0.00000002816%	0.0000000762	0.0000000179
50	28.74%	0.00000002874%	0.0000000777	0.0000000177
51	29.31%	0.00000002931%	0.0000000793	0.0000000176
52	29.89%	0.00000002989%	0.0000000808	0.0000000174
53	30.46%	0.00000003046%	0.0000000824	0.0000000172
54	31.03%	0.00000003103%	0.0000000839	0.0000000170
55	31.61%	0.00000003161%	0.0000000855	0.0000000168
56	32.18%	0.00000003218%	0.0000000871	0.0000000166
57	32.76%	0.00000003276%	0.0000000886	0.0000000164
58	33.33%	0.00000003333%	0.0000000902	0.0000000162
59	33.91%	0.00000003391%	0.0000000917	0.0000000160
60	34.48%	0.00000003448%	0.0000000933	0.0000000158
61	35.06%	0.00000003506%	0.0000000948	0.0000000156
62	35.63%	0.00000003563%	0.0000000964	0.0000000154
63	36.21%	0.00000003621%	0.0000000979	0.0000000152
64	36.78%	0.00000003678%	0.0000000995	0.0000000150
65	37.36%	0.00000003736%	0.0000001010	0.0000000148
66	37.93%	0.00000003793%	0.0000001026	0.0000000146
67	38.51%	0.00000003851%	0.0000001042	0.0000000144
68	39.08%	0.00000003908%	0.0000001057	0.0000000142
69	39.66%	0.00000003966%	0.0000001073	0.0000000140
70	40.23%	0.00000004023%	0.0000001088	0.0000000137
71	40.80%	0.00000004080%	0.0000001104	0.0000000135
72	41.38%	0.00000004138%	0.0000001119	0.0000000133
73	41.95%	0.00000004195%	0.0000001135	0.0000000131
74	42.53%	0.00000004253%	0.0000001150	0.0000000129
75	43.10%	0.00000004310%	0.0000001166	0.0000000127
76	43.68%	0.00000004368%	0.0000001181	0.0000000125
77	44.25%	0.00000004425%	0.0000001197	0.0000000123
78	44.83%	0.00000004483%	0.0000001213	0.0000000121
79	45.40%	0.00000004540%	0.0000001228	0.0000000119
80	45.98%	0.00000004598%	0.0000001244	0.0000000117
81	46.55%	0.00000004655%	0.0000001259	0.0000000115
82	47.13%	0.00000004713%	0.0000001275	0.0000000113
83	47.70%	0.00000004770%	0.0000001290	0.0000000111
84	48.28%	0.00000004828%	0.0000001306	0.0000000109
85	48.85%	0.00000004885%	0.0000001321	0.0000000107

86	49.43%	0.00000004943%	0.0000001337	0.0000000105
87	50.00%	0.00000005000%	0.0000001353	0.0000000103
88	50.57%	0.00000005057%	0.0000001368	0.0000000101
89	51.15%	0.00000005115%	0.0000001384	0.0000000100
90	51.72%	0.00000005172%	0.0000001399	0.0000000098
91	52.30%	0.00000005230%	0.0000001415	0.0000000096
92	52.87%	0.00000005287%	0.0000001430	0.0000000094
93	53.45%	0.00000005345%	0.0000001446	0.0000000093
94	54.02%	0.00000005402%	0.0000001461	0.0000000091
95	54.60%	0.00000005460%	0.0000001477	0.0000000089
96	55.17%	0.00000005517%	0.0000001492	0.0000000087
97	55.75%	0.00000005575%	0.0000001508	0.0000000086
98	56.32%	0.00000005632%	0.0000001524	0.0000000084
99	56.90%	0.00000005690%	0.0000001539	0.0000000082
100	57.47%	0.00000005747%	0.0000001555	0.0000000081
101	58.05%	0.00000005805%	0.0000001570	0.0000000079
102	58.62%	0.00000005862%	0.0000001586	0.0000000078
103	59.20%	0.00000005920%	0.0000001601	0.0000000076
104	59.77%	0.00000005977%	0.0000001617	0.0000000075
105	60.34%	0.00000006034%	0.0000001632	0.0000000073
106	60.92%	0.00000006092%	0.0000001648	0.0000000072
107	61.49%	0.00000006149%	0.0000001663	0.0000000070
108	62.07%	0.00000006207%	0.0000001679	0.0000000069
109	62.64%	0.00000006264%	0.0000001695	0.0000000068
110	63.22%	0.00000006322%	0.0000001710	0.0000000066
111	63.79%	0.00000006379%	0.0000001726	0.0000000065
112	64.37%	0.00000006437%	0.0000001741	0.0000000064
113	64.94%	0.00000006494%	0.0000001757	0.0000000062
114	65.52%	0.00000006552%	0.0000001772	0.0000000061
115	66.09%	0.00000006609%	0.0000001788	0.0000000060
116	66.67%	0.00000006667%	0.0000001803	0.0000000058
117	67.24%	0.00000006724%	0.0000001819	0.0000000057
118	67.82%	0.00000006782%	0.0000001834	0.0000000056
119	68.39%	0.00000006839%	0.0000001850	0.0000000055
120	68.97%	0.00000006897%	0.0000001866	0.0000000054
121	69.54%	0.00000006954%	0.0000001881	0.0000000053
122	70.11%	0.00000007011%	0.0000001897	0.0000000052
123	70.69%	0.00000007069%	0.0000001912	0.0000000050
124	71.26%	0.00000007126%	0.0000001928	0.0000000049
125	71.84%	0.00000007184%	0.0000001943	0.0000000048
126	72.41%	0.00000007241%	0.0000001959	0.0000000047
127	72.99%	0.00000007299%	0.0000001974	0.0000000046
128	73.56%	0.00000007356%	0.0000001990	0.0000000045
129	74.14%	0.00000007414%	0.0000002005	0.0000000044
130	74.71%	0.00000007471%	0.0000002021	0.0000000043
131	75.29%	0.00000007529%	0.0000002037	0.0000000042
132	75.86%	0.00000007586%	0.0000002052	0.0000000041
133	76.44%	0.00000007644%	0.0000002068	0.0000000041
134	77.01%	0.00000007701%	0.0000002083	0.0000000040
135	77.59%	0.00000007759%	0.0000002099	0.0000000039
136	78.16%	0.00000007816%	0.0000002114	0.0000000038
137	78.74%	0.00000007874%	0.0000002130	0.0000000037

138	79.31%	0.00000007931%	0.0000002145	0.0000000036
139	79.89%	0.00000007989%	0.0000002161	0.0000000036
140	80.46%	0.00000008046%	0.0000002176	0.0000000035
141	81.03%	0.00000008103%	0.0000002192	0.0000000034
142	81.61%	0.00000008161%	0.0000002208	0.0000000033
143	82.18%	0.00000008218%	0.0000002223	0.0000000032
144	82.76%	0.00000008276%	0.0000002239	0.0000000032
145	83.33%	0.00000008333%	0.0000002254	0.0000000031
146	83.91%	0.00000008391%	0.0000002270	0.0000000030
147	84.48%	0.00000008448%	0.0000002285	0.0000000030
148	85.06%	0.00000008506%	0.0000002301	0.0000000029
149	85.63%	0.00000008563%	0.0000002316	0.0000000028
150	86.21%	0.00000008621%	0.0000002332	0.0000000028
151	86.78%	0.00000008678%	0.0000002347	0.0000000027
152	87.36%	0.00000008736%	0.0000002363	0.0000000026
153	87.93%	0.00000008793%	0.0000002379	0.0000000026
154	88.51%	0.00000008851%	0.0000002394	0.0000000025
155	89.08%	0.00000008908%	0.0000002410	0.0000000025
156	89.66%	0.00000008966%	0.0000002425	0.0000000024
157	90.23%	0.00000009023%	0.0000002441	0.0000000024
158	90.80%	0.00000009080%	0.0000002456	0.0000000023
159	91.38%	0.00000009138%	0.0000002472	0.0000000022
160	91.95%	0.00000009195%	0.0000002487	0.0000000022
161	92.53%	0.00000009253%	0.0000002503	0.0000000021
162	93.10%	0.00000009310%	0.0000002518	0.0000000021
163	93.68%	0.00000009368%	0.0000002534	0.0000000020
164	94.25%	0.00000009425%	0.0000002550	0.0000000020
165	94.83%	0.00000009483%	0.0000002565	0.0000000020
166	95.40%	0.00000009540%	0.0000002581	0.0000000019
167	95.98%	0.00000009598%	0.0000002596	0.0000000019
168	96.55%	0.00000009655%	0.0000002612	0.0000000018
169	97.13%	0.00000009713%	0.0000002627	0.0000000018
170	97.70%	0.00000009770%	0.0000002643	0.0000000017
171	98.28%	0.00000009828%	0.0000002658	0.0000000017
172	98.85%	0.00000009885%	0.0000002674	0.0000000017
173	99.43%	0.00000009943%	0.0000002689	0.0000000016
174	100.00%	0.00000010000%	0.0000002705	0.0000000016
Beyond (e)				0.0000000526
Total				0.0000017688

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.00000000000%	0.0000000000	0.0000000000
18	0.64%	0.00000000064%	0.0000000016	0.0000000009
19	1.27%	0.00000000127%	0.0000000031	0.0000000018
20	1.91%	0.00000000191%	0.0000000047	0.0000000026

21	2.55%	0.00000000255%	0.0000000062	0.0000000033
22	3.18%	0.00000000318%	0.0000000078	0.0000000041
23	3.82%	0.00000000382%	0.0000000093	0.0000000047
24	4.46%	0.00000000446%	0.0000000109	0.0000000054
25	5.10%	0.00000000510%	0.0000000125	0.0000000060
26	5.73%	0.00000000573%	0.0000000140	0.0000000065
27	6.37%	0.00000000637%	0.0000000156	0.0000000070
28	7.01%	0.00000000701%	0.0000000171	0.0000000075
29	7.64%	0.00000000764%	0.0000000187	0.0000000079
30	8.28%	0.00000000828%	0.0000000202	0.0000000083
31	8.92%	0.00000000892%	0.0000000218	0.0000000087
32	9.55%	0.00000000955%	0.0000000234	0.0000000091
33	10.19%	0.00000001019%	0.0000000249	0.0000000094
34	10.83%	0.00000001083%	0.0000000265	0.0000000097
35	11.46%	0.00000001146%	0.0000000280	0.0000000100
36	12.10%	0.00000001210%	0.0000000296	0.0000000102
37	12.74%	0.00000001274%	0.0000000311	0.0000000104
38	13.38%	0.00000001338%	0.0000000327	0.0000000106
39	14.01%	0.00000001401%	0.0000000343	0.0000000108
40	14.65%	0.00000001465%	0.0000000358	0.0000000110
41	15.29%	0.00000001529%	0.0000000374	0.0000000111
42	15.92%	0.00000001592%	0.0000000389	0.0000000113
43	16.56%	0.00000001656%	0.0000000405	0.0000000114
44	17.20%	0.00000001720%	0.0000000420	0.0000000115
45	17.83%	0.00000001783%	0.0000000436	0.0000000115
46	18.47%	0.00000001847%	0.0000000452	0.0000000116
47	19.11%	0.00000001911%	0.0000000467	0.0000000116
48	19.75%	0.00000001975%	0.0000000483	0.0000000117
49	20.38%	0.00000002038%	0.0000000498	0.0000000117
50	21.02%	0.00000002102%	0.0000000514	0.0000000117
51	21.66%	0.00000002166%	0.0000000529	0.0000000117
52	22.29%	0.00000002229%	0.0000000545	0.0000000117
53	22.93%	0.00000002293%	0.0000000561	0.0000000117
54	23.57%	0.00000002357%	0.0000000576	0.0000000117
55	24.20%	0.00000002420%	0.0000000592	0.0000000116
56	24.84%	0.00000002484%	0.0000000607	0.0000000116
57	25.48%	0.00000002548%	0.0000000623	0.0000000116
58	26.11%	0.00000002611%	0.0000000639	0.0000000115
59	26.75%	0.00000002675%	0.0000000654	0.0000000114
60	27.39%	0.00000002739%	0.0000000670	0.0000000114
61	28.03%	0.00000002803%	0.0000000685	0.0000000113
62	28.66%	0.00000002866%	0.0000000701	0.0000000112
63	29.30%	0.00000002930%	0.0000000716	0.0000000111
64	29.94%	0.00000002994%	0.0000000732	0.0000000110
65	30.57%	0.00000003057%	0.0000000748	0.0000000109
66	31.21%	0.00000003121%	0.0000000763	0.0000000108
67	31.85%	0.00000003185%	0.0000000779	0.0000000107
68	32.48%	0.00000003248%	0.0000000794	0.0000000106
69	33.12%	0.00000003312%	0.0000000810	0.0000000105
70	33.76%	0.00000003376%	0.0000000825	0.0000000104
71	34.39%	0.00000003439%	0.0000000841	0.0000000103
72	35.03%	0.00000003503%	0.0000000857	0.0000000102

73	35.67%	0.00000003567%	0.0000000872	0.0000000101
74	36.31%	0.00000003631%	0.0000000888	0.0000000100
75	36.94%	0.00000003694%	0.0000000903	0.0000000098
76	37.58%	0.00000003758%	0.0000000919	0.0000000097
77	38.22%	0.00000003822%	0.0000000934	0.0000000096
78	38.85%	0.00000003885%	0.0000000950	0.0000000095
79	39.49%	0.00000003949%	0.0000000966	0.0000000093
80	40.13%	0.00000004013%	0.0000000981	0.0000000092
81	40.76%	0.00000004076%	0.0000000997	0.0000000091
82	41.40%	0.00000004140%	0.0000001012	0.0000000090
83	42.04%	0.00000004204%	0.0000001028	0.0000000088
84	42.68%	0.00000004268%	0.0000001043	0.0000000087
85	43.31%	0.00000004331%	0.0000001059	0.0000000086
86	43.95%	0.00000004395%	0.0000001075	0.0000000085
87	44.59%	0.00000004459%	0.0000001090	0.0000000083
88	45.22%	0.00000004522%	0.0000001106	0.0000000082
89	45.86%	0.00000004586%	0.0000001121	0.0000000081
90	46.50%	0.00000004650%	0.0000001137	0.0000000079
91	47.13%	0.00000004713%	0.0000001152	0.0000000078
92	47.77%	0.00000004777%	0.0000001168	0.0000000077
93	48.41%	0.00000004841%	0.0000001184	0.0000000076
94	49.04%	0.00000004904%	0.0000001199	0.0000000075
95	49.68%	0.00000004968%	0.0000001215	0.0000000073
96	50.32%	0.00000005032%	0.0000001230	0.0000000072
97	50.96%	0.00000005096%	0.0000001246	0.0000000071
98	51.59%	0.00000005159%	0.0000001261	0.0000000070
99	52.23%	0.00000005223%	0.0000001277	0.0000000068
100	52.87%	0.00000005287%	0.0000001293	0.0000000067
101	53.50%	0.00000005350%	0.0000001308	0.0000000066
102	54.14%	0.00000005414%	0.0000001324	0.0000000065
103	54.78%	0.00000005478%	0.0000001339	0.0000000064
104	55.41%	0.00000005541%	0.0000001355	0.0000000063
105	56.05%	0.00000005605%	0.0000001370	0.0000000062
106	56.69%	0.00000005669%	0.0000001386	0.0000000060
107	57.32%	0.00000005732%	0.0000001402	0.0000000059
108	57.96%	0.00000005796%	0.0000001417	0.0000000058
109	58.60%	0.00000005860%	0.0000001433	0.0000000057
110	59.24%	0.00000005924%	0.0000001448	0.0000000056
111	59.87%	0.00000005987%	0.0000001464	0.0000000055
112	60.51%	0.00000006051%	0.0000001479	0.0000000054
113	61.15%	0.00000006115%	0.0000001495	0.0000000053
114	61.78%	0.00000006178%	0.0000001511	0.0000000052
115	62.42%	0.00000006242%	0.0000001526	0.0000000051
116	63.06%	0.00000006306%	0.0000001542	0.0000000050
117	63.69%	0.00000006369%	0.0000001557	0.0000000049
118	64.33%	0.00000006433%	0.0000001573	0.0000000048
119	64.97%	0.00000006497%	0.0000001588	0.0000000047
120	65.61%	0.00000006561%	0.0000001604	0.0000000046
121	66.24%	0.00000006624%	0.0000001620	0.0000000045
122	66.88%	0.00000006688%	0.0000001635	0.0000000044
123	67.52%	0.00000006752%	0.0000001651	0.0000000044
124	68.15%	0.00000006815%	0.0000001666	0.0000000043

125	68.79%	0.00000006879%	0.0000001682	0.0000000042
126	69.43%	0.00000006943%	0.0000001697	0.0000000041
127	70.06%	0.00000007006%	0.0000001713	0.0000000040
128	70.70%	0.00000007070%	0.0000001729	0.0000000039
129	71.34%	0.00000007134%	0.0000001744	0.0000000039
130	71.97%	0.00000007197%	0.0000001760	0.0000000038
131	72.61%	0.00000007261%	0.0000001775	0.0000000037
132	73.25%	0.00000007325%	0.0000001791	0.0000000036
133	73.89%	0.00000007389%	0.0000001806	0.0000000035
134	74.52%	0.00000007452%	0.0000001822	0.0000000035
135	75.16%	0.00000007516%	0.0000001838	0.0000000034
136	75.80%	0.00000007580%	0.0000001853	0.0000000033
137	76.43%	0.00000007643%	0.0000001869	0.0000000033
138	77.07%	0.00000007707%	0.0000001884	0.0000000032
139	77.71%	0.00000007771%	0.0000001900	0.0000000031
140	78.34%	0.00000007834%	0.0000001916	0.0000000031
141	78.98%	0.00000007898%	0.0000001931	0.0000000030
142	79.62%	0.00000007962%	0.0000001947	0.0000000029
143	80.25%	0.00000008025%	0.0000001962	0.0000000029
144	80.89%	0.00000008089%	0.0000001978	0.0000000028
145	81.53%	0.00000008153%	0.0000001993	0.0000000027
146	82.17%	0.00000008217%	0.0000002009	0.0000000027
147	82.80%	0.00000008280%	0.0000002025	0.0000000026
148	83.44%	0.00000008344%	0.0000002040	0.0000000026
149	84.08%	0.00000008408%	0.0000002056	0.0000000025
150	84.71%	0.00000008471%	0.0000002071	0.0000000025
151	85.35%	0.00000008535%	0.0000002087	0.0000000024
152	85.99%	0.00000008599%	0.0000002102	0.0000000024
153	86.62%	0.00000008662%	0.0000002118	0.0000000023
154	87.26%	0.00000008726%	0.0000002134	0.0000000022
155	87.90%	0.00000008790%	0.0000002149	0.0000000022
156	88.54%	0.00000008854%	0.0000002165	0.0000000022
157	89.17%	0.00000008917%	0.0000002180	0.0000000021
158	89.81%	0.00000008981%	0.0000002196	0.0000000021
159	90.45%	0.00000009045%	0.0000002211	0.0000000020
160	91.08%	0.00000009108%	0.0000002227	0.0000000020
161	91.72%	0.00000009172%	0.0000002243	0.0000000019
162	92.36%	0.00000009236%	0.0000002258	0.0000000019
163	92.99%	0.00000009299%	0.0000002274	0.0000000018
164	93.63%	0.00000009363%	0.0000002289	0.0000000018
165	94.27%	0.00000009427%	0.0000002305	0.0000000018
166	94.90%	0.00000009490%	0.0000002320	0.0000000017
167	95.54%	0.00000009554%	0.0000002336	0.0000000017
168	96.18%	0.00000009618%	0.0000002352	0.0000000016
169	96.82%	0.00000009682%	0.0000002367	0.0000000016
170	97.45%	0.00000009745%	0.0000002383	0.0000000016
171	98.09%	0.00000009809%	0.0000002398	0.0000000015
172	98.73%	0.00000009873%	0.0000002414	0.0000000015
173	99.36%	0.00000009936%	0.0000002429	0.0000000015
174	100.00%	0.00000010000%	0.0000002445	0.0000000014
Beyond (f)				0.0000000476
Total				0.0000010679

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.0000000000	0.0000000000
1	0.64%	0.00000000064%	0.0000000016	0.0000000015
2	1.27%	0.00000000127%	0.0000000031	0.0000000029
3	1.91%	0.00000000191%	0.0000000047	0.0000000043
4	2.55%	0.00000000255%	0.0000000062	0.0000000055
5	3.18%	0.00000000318%	0.0000000078	0.0000000067
6	3.82%	0.00000000382%	0.0000000093	0.0000000078
7	4.46%	0.00000000446%	0.0000000109	0.0000000089
8	5.10%	0.00000000510%	0.0000000125	0.0000000098
9	5.73%	0.00000000573%	0.0000000140	0.0000000107
10	6.37%	0.00000000637%	0.0000000156	0.0000000116
11	7.01%	0.00000000701%	0.0000000171	0.0000000124
12	7.64%	0.00000000764%	0.0000000187	0.0000000131
13	8.28%	0.00000000828%	0.0000000202	0.0000000138
14	8.92%	0.00000000892%	0.0000000218	0.0000000144
15	9.55%	0.00000000955%	0.0000000234	0.0000000150
16	10.19%	0.00000001019%	0.0000000249	0.0000000155
17	10.83%	0.00000001083%	0.0000000265	0.0000000160
18	11.46%	0.00000001146%	0.0000000280	0.0000000165
19	12.10%	0.00000001210%	0.0000000296	0.0000000169
20	12.74%	0.00000001274%	0.0000000311	0.0000000172
21	13.38%	0.00000001338%	0.0000000327	0.0000000176
22	14.01%	0.00000001401%	0.0000000343	0.0000000179
23	14.65%	0.00000001465%	0.0000000358	0.0000000181
24	15.29%	0.00000001529%	0.0000000374	0.0000000184
25	15.92%	0.00000001592%	0.0000000389	0.0000000186
26	16.56%	0.00000001656%	0.0000000405	0.0000000188
27	17.20%	0.00000001720%	0.0000000420	0.0000000189
28	17.83%	0.00000001783%	0.0000000436	0.0000000191
29	18.47%	0.00000001847%	0.0000000452	0.0000000192
30	19.11%	0.00000001911%	0.0000000467	0.0000000192
31	19.75%	0.00000001975%	0.0000000483	0.0000000193
32	20.38%	0.00000002038%	0.0000000498	0.0000000194
33	21.02%	0.00000002102%	0.0000000514	0.0000000194
34	21.66%	0.00000002166%	0.0000000529	0.0000000194
35	22.29%	0.00000002229%	0.0000000545	0.0000000194
36	22.93%	0.00000002293%	0.0000000561	0.0000000193
37	23.57%	0.00000002357%	0.0000000576	0.0000000193
38	24.20%	0.00000002420%	0.0000000592	0.0000000192
39	24.84%	0.00000002484%	0.0000000607	0.0000000192
40	25.48%	0.00000002548%	0.0000000623	0.0000000191
41	26.11%	0.00000002611%	0.0000000639	0.0000000190
42	26.75%	0.00000002675%	0.0000000654	0.0000000189

43	27.39%	0.00000002739%	0.0000000670	0.0000000188
44	28.03%	0.00000002803%	0.0000000685	0.0000000187
45	28.66%	0.00000002866%	0.0000000701	0.0000000185
46	29.30%	0.00000002930%	0.0000000716	0.0000000184
47	29.94%	0.00000002994%	0.0000000732	0.0000000182
48	30.57%	0.00000003057%	0.0000000748	0.0000000181
49	31.21%	0.00000003121%	0.0000000763	0.0000000179
50	31.85%	0.00000003185%	0.0000000779	0.0000000178
51	32.48%	0.00000003248%	0.0000000794	0.0000000176
52	33.12%	0.00000003312%	0.0000000810	0.0000000174
53	33.76%	0.00000003376%	0.0000000825	0.0000000172
54	34.39%	0.00000003439%	0.0000000841	0.0000000170
55	35.03%	0.00000003503%	0.0000000857	0.0000000169
56	35.67%	0.00000003567%	0.0000000872	0.0000000167
57	36.31%	0.00000003631%	0.0000000888	0.0000000165
58	36.94%	0.00000003694%	0.0000000903	0.0000000163
59	37.58%	0.00000003758%	0.0000000919	0.0000000161
60	38.22%	0.00000003822%	0.0000000934	0.0000000159
61	38.85%	0.00000003885%	0.0000000950	0.0000000157
62	39.49%	0.00000003949%	0.0000000966	0.0000000154
63	40.13%	0.00000004013%	0.0000000981	0.0000000152
64	40.76%	0.00000004076%	0.0000000997	0.0000000150
65	41.40%	0.00000004140%	0.0000001012	0.0000000148
66	42.04%	0.00000004204%	0.0000001028	0.0000000146
67	42.68%	0.00000004268%	0.0000001043	0.0000000144
68	43.31%	0.00000004331%	0.0000001059	0.0000000142
69	43.95%	0.00000004395%	0.0000001075	0.0000000140
70	44.59%	0.00000004459%	0.0000001090	0.0000000138
71	45.22%	0.00000004522%	0.0000001106	0.0000000136
72	45.86%	0.00000004586%	0.0000001121	0.0000000133
73	46.50%	0.00000004650%	0.0000001137	0.0000000131
74	47.13%	0.00000004713%	0.0000001152	0.0000000129
75	47.77%	0.00000004777%	0.0000001168	0.0000000127
76	48.41%	0.00000004841%	0.0000001184	0.0000000125
77	49.04%	0.00000004904%	0.0000001199	0.0000000123
78	49.68%	0.00000004968%	0.0000001215	0.0000000121
79	50.32%	0.00000005032%	0.0000001230	0.0000000119
80	50.96%	0.00000005096%	0.0000001246	0.0000000117
81	51.59%	0.00000005159%	0.0000001261	0.0000000115
82	52.23%	0.00000005223%	0.0000001277	0.0000000113
83	52.87%	0.00000005287%	0.0000001293	0.0000000111
84	53.50%	0.00000005350%	0.0000001308	0.0000000109
85	54.14%	0.00000005414%	0.0000001324	0.0000000107
86	54.78%	0.00000005478%	0.0000001339	0.0000000105
87	55.41%	0.00000005541%	0.0000001355	0.0000000104
88	56.05%	0.00000005605%	0.0000001370	0.0000000102
89	56.69%	0.00000005669%	0.0000001386	0.0000000100
90	57.32%	0.00000005732%	0.0000001402	0.0000000098
91	57.96%	0.00000005796%	0.0000001417	0.0000000096
92	58.60%	0.00000005860%	0.0000001433	0.0000000094
93	59.24%	0.00000005924%	0.0000001448	0.0000000093
94	59.87%	0.00000005987%	0.0000001464	0.0000000091

95	60.51%	0.00000006051%	0.0000001479	0.0000000089
96	61.15%	0.00000006115%	0.0000001495	0.0000000088
97	61.78%	0.00000006178%	0.0000001511	0.0000000086
98	62.42%	0.00000006242%	0.0000001526	0.0000000084
99	63.06%	0.00000006306%	0.0000001542	0.0000000083
100	63.69%	0.00000006369%	0.0000001557	0.0000000081
101	64.33%	0.00000006433%	0.0000001573	0.0000000079
102	64.97%	0.00000006497%	0.0000001588	0.0000000078
103	65.61%	0.00000006561%	0.0000001604	0.0000000076
104	66.24%	0.00000006624%	0.0000001620	0.0000000075
105	66.88%	0.00000006688%	0.0000001635	0.0000000073
106	67.52%	0.00000006752%	0.0000001651	0.0000000072
107	68.15%	0.00000006815%	0.0000001666	0.0000000070
108	68.79%	0.00000006879%	0.0000001682	0.0000000069
109	69.43%	0.00000006943%	0.0000001697	0.0000000068
110	70.06%	0.00000007006%	0.0000001713	0.0000000066
111	70.70%	0.00000007070%	0.0000001729	0.0000000065
112	71.34%	0.00000007134%	0.0000001744	0.0000000064
113	71.97%	0.00000007197%	0.0000001760	0.0000000062
114	72.61%	0.00000007261%	0.0000001775	0.0000000061
115	73.25%	0.00000007325%	0.0000001791	0.0000000060
116	73.89%	0.00000007389%	0.0000001806	0.0000000059
117	74.52%	0.00000007452%	0.0000001822	0.0000000057
118	75.16%	0.00000007516%	0.0000001838	0.0000000056
119	75.80%	0.00000007580%	0.0000001853	0.0000000055
120	76.43%	0.00000007643%	0.0000001869	0.0000000054
121	77.07%	0.00000007707%	0.0000001884	0.0000000053
122	77.71%	0.00000007771%	0.0000001900	0.0000000052
123	78.34%	0.00000007834%	0.0000001916	0.0000000051
124	78.98%	0.00000007898%	0.0000001931	0.0000000049
125	79.62%	0.00000007962%	0.0000001947	0.0000000048
126	80.25%	0.00000008025%	0.0000001962	0.0000000047
127	80.89%	0.00000008089%	0.0000001978	0.0000000046
128	81.53%	0.00000008153%	0.0000001993	0.0000000045
129	82.17%	0.00000008217%	0.0000002009	0.0000000044
130	82.80%	0.00000008280%	0.0000002025	0.0000000043
131	83.44%	0.00000008344%	0.0000002040	0.0000000042
132	84.08%	0.00000008408%	0.0000002056	0.0000000042
133	84.71%	0.00000008471%	0.0000002071	0.0000000041
134	85.35%	0.00000008535%	0.0000002087	0.0000000040
135	85.99%	0.00000008599%	0.0000002102	0.0000000039
136	86.62%	0.00000008662%	0.0000002118	0.0000000038
137	87.26%	0.00000008726%	0.0000002134	0.0000000037
138	87.90%	0.00000008790%	0.0000002149	0.0000000036
139	88.54%	0.00000008854%	0.0000002165	0.0000000036
140	89.17%	0.00000008917%	0.0000002180	0.0000000035
141	89.81%	0.00000008981%	0.0000002196	0.0000000034
142	90.45%	0.00000009045%	0.0000002211	0.0000000033
143	91.08%	0.00000009108%	0.0000002227	0.0000000033
144	91.72%	0.00000009172%	0.0000002243	0.0000000032
145	92.36%	0.00000009236%	0.0000002258	0.0000000031
146	92.99%	0.00000009299%	0.0000002274	0.0000000030

147	93.63%	0.00000009363%	0.0000002289	0.0000000030
148	94.27%	0.00000009427%	0.0000002305	0.0000000029
149	94.90%	0.00000009490%	0.0000002320	0.0000000028
150	95.54%	0.00000009554%	0.0000002336	0.0000000028
151	96.18%	0.00000009618%	0.0000002352	0.0000000027
152	96.82%	0.00000009682%	0.0000002367	0.0000000026
153	97.45%	0.00000009745%	0.0000002383	0.0000000026
154	98.09%	0.00000009809%	0.0000002398	0.0000000025
155	98.73%	0.00000009873%	0.0000002414	0.0000000025
156	99.36%	0.00000009936%	0.0000002429	0.0000000024
157	100.00%	0.00000010000%	0.0000002445	0.0000000024
Beyond (g)				0.0000000787
Total				0.0000017651

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres): 0.00000632

Lake Ashtabula - Jump Dispersal (acres): 0.00000716

Lower Sheyenne River - Progressive Dispersal (river-miles):	0.0000000803
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.0000000485
Upper Sheyenne River - Jump Dispersal (river-miles):	0.0000000801

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 175 into perpetuity

(f) From year 175 into perpetuity

(g) From year 158 into perpetuity

(h) From year 26 into perpetuity

Appendix 3C. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Slow Invasion - Low Risk (One Organism)

Probability of successful invasion:	1.00E-06
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.0000000	0.0000000
1	5.88%	0.00000588%	0.0003079	0.0002989
2	11.76%	0.00001176%	0.0006158	0.0005804
3	17.65%	0.00001765%	0.0009236	0.0008453
4	23.53%	0.00002353%	0.0012315	0.0010942
5	29.41%	0.00002941%	0.0015394	0.0013279
6	35.29%	0.00003529%	0.0018473	0.0015471
7	41.18%	0.00004118%	0.0021552	0.0017524
8	47.06%	0.00004706%	0.0024631	0.0019444
9	52.94%	0.00005294%	0.0027709	0.0021237
10	58.82%	0.00005882%	0.0030788	0.0022909
11	64.71%	0.00006471%	0.0033867	0.0024466
12	70.59%	0.00007059%	0.0036946	0.0025913
13	76.47%	0.00007647%	0.0040025	0.0027255
14	82.35%	0.00008235%	0.0043104	0.0028497
15	88.24%	0.00008824%	0.0046182	0.0029643
16	94.12%	0.00009412%	0.0049261	0.0030698
17	100.00%	0.00010000%	0.0052340	0.0031667
Beyond (c)				0.1055552
Total				0.1391741

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.0000000	0.0000000
1	12.50%	0.00001250%	0.0006543	0.0006352

2	25.00%	0.00002500%	0.0013085	0.0012334
3	37.50%	0.00003750%	0.0019628	0.0017962
4	50.00%	0.00005000%	0.0026170	0.0023252
5	62.50%	0.00006250%	0.0032713	0.0028218
6	75.00%	0.00007500%	0.0039255	0.0032875
7	87.50%	0.00008750%	0.0045798	0.0037238
8	100.00%	0.00010000%	0.0052340	0.0041318
Beyond (d)				0.1377256
Total				0.1576804

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.0000000	0.0000000
1	0.57%	0.00000057%	0.0000016	0.0000015
2	1.15%	0.00000115%	0.0000031	0.0000029
3	1.72%	0.00000172%	0.0000047	0.0000043
4	2.30%	0.00000230%	0.0000062	0.0000055
5	2.87%	0.00000287%	0.0000078	0.0000067
6	3.45%	0.00000345%	0.0000093	0.0000078
7	4.02%	0.00000402%	0.0000109	0.0000088
8	4.60%	0.00000460%	0.0000124	0.0000098
9	5.17%	0.00000517%	0.0000140	0.0000107
10	5.75%	0.00000575%	0.0000155	0.0000116
11	6.32%	0.00000632%	0.0000171	0.0000124
12	6.90%	0.00000690%	0.0000187	0.0000131
13	7.47%	0.00000747%	0.0000202	0.0000138
14	8.05%	0.00000805%	0.0000218	0.0000144
15	8.62%	0.00000862%	0.0000233	0.0000150
16	9.20%	0.00000920%	0.0000249	0.0000155
17	9.77%	0.00000977%	0.0000264	0.0000160
18	10.34%	0.00001034%	0.0000280	0.0000164
19	10.92%	0.00001092%	0.0000295	0.0000168
20	11.49%	0.00001149%	0.0000311	0.0000172
21	12.07%	0.00001207%	0.0000326	0.0000175
22	12.64%	0.00001264%	0.0000342	0.0000178
23	13.22%	0.00001322%	0.0000358	0.0000181
24	13.79%	0.00001379%	0.0000373	0.0000184
25	14.37%	0.00001437%	0.0000389	0.0000186
26	14.94%	0.00001494%	0.0000404	0.0000187
27	15.52%	0.00001552%	0.0000420	0.0000189
28	16.09%	0.00001609%	0.0000435	0.0000190
29	16.67%	0.00001667%	0.0000451	0.0000191
30	17.24%	0.00001724%	0.0000466	0.0000192
31	17.82%	0.00001782%	0.0000482	0.0000193
32	18.39%	0.00001839%	0.0000497	0.0000193
33	18.97%	0.00001897%	0.0000513	0.0000193

34	19.54%	0.00001954%	0.0000529	0.0000193
35	20.11%	0.00002011%	0.0000544	0.0000193
36	20.69%	0.00002069%	0.0000560	0.0000193
37	21.26%	0.00002126%	0.0000575	0.0000193
38	21.84%	0.00002184%	0.0000591	0.0000192
39	22.41%	0.00002241%	0.0000606	0.0000191
40	22.99%	0.00002299%	0.0000622	0.0000191
41	23.56%	0.00002356%	0.0000637	0.0000190
42	24.14%	0.00002414%	0.0000653	0.0000189
43	24.71%	0.00002471%	0.0000668	0.0000188
44	25.29%	0.00002529%	0.0000684	0.0000186
45	25.86%	0.00002586%	0.0000700	0.0000185
46	26.44%	0.00002644%	0.0000715	0.0000184
47	27.01%	0.00002701%	0.0000731	0.0000182
48	27.59%	0.00002759%	0.0000746	0.0000181
49	28.16%	0.00002816%	0.0000762	0.0000179
50	28.74%	0.00002874%	0.0000777	0.0000177
51	29.31%	0.00002931%	0.0000793	0.0000176
52	29.89%	0.00002989%	0.0000808	0.0000174
53	30.46%	0.00003046%	0.0000824	0.0000172
54	31.03%	0.00003103%	0.0000839	0.0000170
55	31.61%	0.00003161%	0.0000855	0.0000168
56	32.18%	0.00003218%	0.0000871	0.0000166
57	32.76%	0.00003276%	0.0000886	0.0000164
58	33.33%	0.00003333%	0.0000902	0.0000162
59	33.91%	0.00003391%	0.0000917	0.0000160
60	34.48%	0.00003448%	0.0000933	0.0000158
61	35.06%	0.00003506%	0.0000948	0.0000156
62	35.63%	0.00003563%	0.0000964	0.0000154
63	36.21%	0.00003621%	0.0000979	0.0000152
64	36.78%	0.00003678%	0.0000995	0.0000150
65	37.36%	0.00003736%	0.0001010	0.0000148
66	37.93%	0.00003793%	0.0001026	0.0000146
67	38.51%	0.00003851%	0.0001042	0.0000144
68	39.08%	0.00003908%	0.0001057	0.0000142
69	39.66%	0.00003966%	0.0001073	0.0000140
70	40.23%	0.00004023%	0.0001088	0.0000137
71	40.80%	0.00004080%	0.0001104	0.0000135
72	41.38%	0.00004138%	0.0001119	0.0000133
73	41.95%	0.00004195%	0.0001135	0.0000131
74	42.53%	0.00004253%	0.0001150	0.0000129
75	43.10%	0.00004310%	0.0001166	0.0000127
76	43.68%	0.00004368%	0.0001181	0.0000125
77	44.25%	0.00004425%	0.0001197	0.0000123
78	44.83%	0.00004483%	0.0001213	0.0000121
79	45.40%	0.00004540%	0.0001228	0.0000119
80	45.98%	0.00004598%	0.0001244	0.0000117
81	46.55%	0.00004655%	0.0001259	0.0000115
82	47.13%	0.00004713%	0.0001275	0.0000113
83	47.70%	0.00004770%	0.0001290	0.0000111
84	48.28%	0.00004828%	0.0001306	0.0000109
85	48.85%	0.00004885%	0.0001321	0.0000107

86	49.43%	0.00004943%	0.0001337	0.0000105
87	50.00%	0.00005000%	0.0001353	0.0000103
88	50.57%	0.00005057%	0.0001368	0.0000101
89	51.15%	0.00005115%	0.0001384	0.0000100
90	51.72%	0.00005172%	0.0001399	0.0000098
91	52.30%	0.00005230%	0.0001415	0.0000096
92	52.87%	0.00005287%	0.0001430	0.0000094
93	53.45%	0.00005345%	0.0001446	0.0000093
94	54.02%	0.00005402%	0.0001461	0.0000091
95	54.60%	0.00005460%	0.0001477	0.0000089
96	55.17%	0.00005517%	0.0001492	0.0000087
97	55.75%	0.00005575%	0.0001508	0.0000086
98	56.32%	0.00005632%	0.0001524	0.0000084
99	56.90%	0.00005690%	0.0001539	0.0000082
100	57.47%	0.00005747%	0.0001555	0.0000081
101	58.05%	0.00005805%	0.0001570	0.0000079
102	58.62%	0.00005862%	0.0001586	0.0000078
103	59.20%	0.00005920%	0.0001601	0.0000076
104	59.77%	0.00005977%	0.0001617	0.0000075
105	60.34%	0.00006034%	0.0001632	0.0000073
106	60.92%	0.00006092%	0.0001648	0.0000072
107	61.49%	0.00006149%	0.0001663	0.0000070
108	62.07%	0.00006207%	0.0001679	0.0000069
109	62.64%	0.00006264%	0.0001695	0.0000068
110	63.22%	0.00006322%	0.0001710	0.0000066
111	63.79%	0.00006379%	0.0001726	0.0000065
112	64.37%	0.00006437%	0.0001741	0.0000064
113	64.94%	0.00006494%	0.0001757	0.0000062
114	65.52%	0.00006552%	0.0001772	0.0000061
115	66.09%	0.00006609%	0.0001788	0.0000060
116	66.67%	0.00006667%	0.0001803	0.0000058
117	67.24%	0.00006724%	0.0001819	0.0000057
118	67.82%	0.00006782%	0.0001834	0.0000056
119	68.39%	0.00006839%	0.0001850	0.0000055
120	68.97%	0.00006897%	0.0001866	0.0000054
121	69.54%	0.00006954%	0.0001881	0.0000053
122	70.11%	0.00007011%	0.0001897	0.0000052
123	70.69%	0.00007069%	0.0001912	0.0000050
124	71.26%	0.00007126%	0.0001928	0.0000049
125	71.84%	0.00007184%	0.0001943	0.0000048
126	72.41%	0.00007241%	0.0001959	0.0000047
127	72.99%	0.00007299%	0.0001974	0.0000046
128	73.56%	0.00007356%	0.0001990	0.0000045
129	74.14%	0.00007414%	0.0002005	0.0000044
130	74.71%	0.00007471%	0.0002021	0.0000043
131	75.29%	0.00007529%	0.0002037	0.0000042
132	75.86%	0.00007586%	0.0002052	0.0000041
133	76.44%	0.00007644%	0.0002068	0.0000041
134	77.01%	0.00007701%	0.0002083	0.0000040
135	77.59%	0.00007759%	0.0002099	0.0000039
136	78.16%	0.00007816%	0.0002114	0.0000038
137	78.74%	0.00007874%	0.0002130	0.0000037

138	79.31%	0.00007931%	0.0002145	0.0000036
139	79.89%	0.00007989%	0.0002161	0.0000036
140	80.46%	0.00008046%	0.0002176	0.0000035
141	81.03%	0.00008103%	0.0002192	0.0000034
142	81.61%	0.00008161%	0.0002208	0.0000033
143	82.18%	0.00008218%	0.0002223	0.0000032
144	82.76%	0.00008276%	0.0002239	0.0000032
145	83.33%	0.00008333%	0.0002254	0.0000031
146	83.91%	0.00008391%	0.0002270	0.0000030
147	84.48%	0.00008448%	0.0002285	0.0000030
148	85.06%	0.00008506%	0.0002301	0.0000029
149	85.63%	0.00008563%	0.0002316	0.0000028
150	86.21%	0.00008621%	0.0002332	0.0000028
151	86.78%	0.00008678%	0.0002347	0.0000027
152	87.36%	0.00008736%	0.0002363	0.0000026
153	87.93%	0.00008793%	0.0002379	0.0000026
154	88.51%	0.00008851%	0.0002394	0.0000025
155	89.08%	0.00008908%	0.0002410	0.0000025
156	89.66%	0.00008966%	0.0002425	0.0000024
157	90.23%	0.00009023%	0.0002441	0.0000024
158	90.80%	0.00009080%	0.0002456	0.0000023
159	91.38%	0.00009138%	0.0002472	0.0000022
160	91.95%	0.00009195%	0.0002487	0.0000022
161	92.53%	0.00009253%	0.0002503	0.0000021
162	93.10%	0.00009310%	0.0002518	0.0000021
163	93.68%	0.00009368%	0.0002534	0.0000020
164	94.25%	0.00009425%	0.0002550	0.0000020
165	94.83%	0.00009483%	0.0002565	0.0000020
166	95.40%	0.00009540%	0.0002581	0.0000019
167	95.98%	0.00009598%	0.0002596	0.0000019
168	96.55%	0.00009655%	0.0002612	0.0000018
169	97.13%	0.00009713%	0.0002627	0.0000018
170	97.70%	0.00009770%	0.0002643	0.0000017
171	98.28%	0.00009828%	0.0002658	0.0000017
172	98.85%	0.00009885%	0.0002674	0.0000017
173	99.43%	0.00009943%	0.0002689	0.0000016
174	100.00%	0.00010000%	0.0002705	0.0000016
Beyond (e)				0.0000526
Total				0.0017688

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.00000000%	0.0000000	0.0000000
18	0.64%	0.00000064%	0.0000016	0.0000009
19	1.27%	0.00000127%	0.0000031	0.0000018
20	1.91%	0.00000191%	0.0000047	0.0000026

21	2.55%	0.00000255%	0.0000062	0.0000033
22	3.18%	0.00000318%	0.0000078	0.0000041
23	3.82%	0.00000382%	0.0000093	0.0000047
24	4.46%	0.00000446%	0.0000109	0.0000054
25	5.10%	0.00000510%	0.0000125	0.0000060
26	5.73%	0.00000573%	0.0000140	0.0000065
27	6.37%	0.00000637%	0.0000156	0.0000070
28	7.01%	0.00000701%	0.0000171	0.0000075
29	7.64%	0.00000764%	0.0000187	0.0000079
30	8.28%	0.00000828%	0.0000202	0.0000083
31	8.92%	0.00000892%	0.0000218	0.0000087
32	9.55%	0.00000955%	0.0000234	0.0000091
33	10.19%	0.00001019%	0.0000249	0.0000094
34	10.83%	0.00001083%	0.0000265	0.0000097
35	11.46%	0.00001146%	0.0000280	0.0000100
36	12.10%	0.00001210%	0.0000296	0.0000102
37	12.74%	0.00001274%	0.0000311	0.0000104
38	13.38%	0.00001338%	0.0000327	0.0000106
39	14.01%	0.00001401%	0.0000343	0.0000108
40	14.65%	0.00001465%	0.0000358	0.0000110
41	15.29%	0.00001529%	0.0000374	0.0000111
42	15.92%	0.00001592%	0.0000389	0.0000113
43	16.56%	0.00001656%	0.0000405	0.0000114
44	17.20%	0.00001720%	0.0000420	0.0000115
45	17.83%	0.00001783%	0.0000436	0.0000115
46	18.47%	0.00001847%	0.0000452	0.0000116
47	19.11%	0.00001911%	0.0000467	0.0000116
48	19.75%	0.00001975%	0.0000483	0.0000117
49	20.38%	0.00002038%	0.0000498	0.0000117
50	21.02%	0.00002102%	0.0000514	0.0000117
51	21.66%	0.00002166%	0.0000529	0.0000117
52	22.29%	0.00002229%	0.0000545	0.0000117
53	22.93%	0.00002293%	0.0000561	0.0000117
54	23.57%	0.00002357%	0.0000576	0.0000117
55	24.20%	0.00002420%	0.0000592	0.0000116
56	24.84%	0.00002484%	0.0000607	0.0000116
57	25.48%	0.00002548%	0.0000623	0.0000116
58	26.11%	0.00002611%	0.0000639	0.0000115
59	26.75%	0.00002675%	0.0000654	0.0000114
60	27.39%	0.00002739%	0.0000670	0.0000114
61	28.03%	0.00002803%	0.0000685	0.0000113
62	28.66%	0.00002866%	0.0000701	0.0000112
63	29.30%	0.00002930%	0.0000716	0.0000111
64	29.94%	0.00002994%	0.0000732	0.0000110
65	30.57%	0.00003057%	0.0000748	0.0000109
66	31.21%	0.00003121%	0.0000763	0.0000108
67	31.85%	0.00003185%	0.0000779	0.0000107
68	32.48%	0.00003248%	0.0000794	0.0000106
69	33.12%	0.00003312%	0.0000810	0.0000105
70	33.76%	0.00003376%	0.0000825	0.0000104
71	34.39%	0.00003439%	0.0000841	0.0000103
72	35.03%	0.00003503%	0.0000857	0.0000102

73	35.67%	0.00003567%	0.0000872	0.0000101
74	36.31%	0.00003631%	0.0000888	0.0000100
75	36.94%	0.00003694%	0.0000903	0.0000098
76	37.58%	0.00003758%	0.0000919	0.0000097
77	38.22%	0.00003822%	0.0000934	0.0000096
78	38.85%	0.00003885%	0.0000950	0.0000095
79	39.49%	0.00003949%	0.0000966	0.0000093
80	40.13%	0.00004013%	0.0000981	0.0000092
81	40.76%	0.00004076%	0.0000997	0.0000091
82	41.40%	0.00004140%	0.0001012	0.0000090
83	42.04%	0.00004204%	0.0001028	0.0000088
84	42.68%	0.00004268%	0.0001043	0.0000087
85	43.31%	0.00004331%	0.0001059	0.0000086
86	43.95%	0.00004395%	0.0001075	0.0000085
87	44.59%	0.00004459%	0.0001090	0.0000083
88	45.22%	0.00004522%	0.0001106	0.0000082
89	45.86%	0.00004586%	0.0001121	0.0000081
90	46.50%	0.00004650%	0.0001137	0.0000079
91	47.13%	0.00004713%	0.0001152	0.0000078
92	47.77%	0.00004777%	0.0001168	0.0000077
93	48.41%	0.00004841%	0.0001184	0.0000076
94	49.04%	0.00004904%	0.0001199	0.0000075
95	49.68%	0.00004968%	0.0001215	0.0000073
96	50.32%	0.00005032%	0.0001230	0.0000072
97	50.96%	0.00005096%	0.0001246	0.0000071
98	51.59%	0.00005159%	0.0001261	0.0000070
99	52.23%	0.00005223%	0.0001277	0.0000068
100	52.87%	0.00005287%	0.0001293	0.0000067
101	53.50%	0.00005350%	0.0001308	0.0000066
102	54.14%	0.00005414%	0.0001324	0.0000065
103	54.78%	0.00005478%	0.0001339	0.0000064
104	55.41%	0.00005541%	0.0001355	0.0000063
105	56.05%	0.00005605%	0.0001370	0.0000062
106	56.69%	0.00005669%	0.0001386	0.0000060
107	57.32%	0.00005732%	0.0001402	0.0000059
108	57.96%	0.00005796%	0.0001417	0.0000058
109	58.60%	0.00005860%	0.0001433	0.0000057
110	59.24%	0.00005924%	0.0001448	0.0000056
111	59.87%	0.00005987%	0.0001464	0.0000055
112	60.51%	0.00006051%	0.0001479	0.0000054
113	61.15%	0.00006115%	0.0001495	0.0000053
114	61.78%	0.00006178%	0.0001511	0.0000052
115	62.42%	0.00006242%	0.0001526	0.0000051
116	63.06%	0.00006306%	0.0001542	0.0000050
117	63.69%	0.00006369%	0.0001557	0.0000049
118	64.33%	0.00006433%	0.0001573	0.0000048
119	64.97%	0.00006497%	0.0001588	0.0000047
120	65.61%	0.00006561%	0.0001604	0.0000046
121	66.24%	0.00006624%	0.0001620	0.0000045
122	66.88%	0.00006688%	0.0001635	0.0000044
123	67.52%	0.00006752%	0.0001651	0.0000044
124	68.15%	0.00006815%	0.0001666	0.0000043

125	68.79%	0.00006879%	0.0001682	0.0000042
126	69.43%	0.00006943%	0.0001697	0.0000041
127	70.06%	0.00007006%	0.0001713	0.0000040
128	70.70%	0.00007070%	0.0001729	0.0000039
129	71.34%	0.00007134%	0.0001744	0.0000039
130	71.97%	0.00007197%	0.0001760	0.0000038
131	72.61%	0.00007261%	0.0001775	0.0000037
132	73.25%	0.00007325%	0.0001791	0.0000036
133	73.89%	0.00007389%	0.0001806	0.0000035
134	74.52%	0.00007452%	0.0001822	0.0000035
135	75.16%	0.00007516%	0.0001838	0.0000034
136	75.80%	0.00007580%	0.0001853	0.0000033
137	76.43%	0.00007643%	0.0001869	0.0000033
138	77.07%	0.00007707%	0.0001884	0.0000032
139	77.71%	0.00007771%	0.0001900	0.0000031
140	78.34%	0.00007834%	0.0001916	0.0000031
141	78.98%	0.00007898%	0.0001931	0.0000030
142	79.62%	0.00007962%	0.0001947	0.0000029
143	80.25%	0.00008025%	0.0001962	0.0000029
144	80.89%	0.00008089%	0.0001978	0.0000028
145	81.53%	0.00008153%	0.0001993	0.0000027
146	82.17%	0.00008217%	0.0002009	0.0000027
147	82.80%	0.00008280%	0.0002025	0.0000026
148	83.44%	0.00008344%	0.0002040	0.0000026
149	84.08%	0.00008408%	0.0002056	0.0000025
150	84.71%	0.00008471%	0.0002071	0.0000025
151	85.35%	0.00008535%	0.0002087	0.0000024
152	85.99%	0.00008599%	0.0002102	0.0000024
153	86.62%	0.00008662%	0.0002118	0.0000023
154	87.26%	0.00008726%	0.0002134	0.0000022
155	87.90%	0.00008790%	0.0002149	0.0000022
156	88.54%	0.00008854%	0.0002165	0.0000022
157	89.17%	0.00008917%	0.0002180	0.0000021
158	89.81%	0.00008981%	0.0002196	0.0000021
159	90.45%	0.00009045%	0.0002211	0.0000020
160	91.08%	0.00009108%	0.0002227	0.0000020
161	91.72%	0.00009172%	0.0002243	0.0000019
162	92.36%	0.00009236%	0.0002258	0.0000019
163	92.99%	0.00009299%	0.0002274	0.0000018
164	93.63%	0.00009363%	0.0002289	0.0000018
165	94.27%	0.00009427%	0.0002305	0.0000018
166	94.90%	0.00009490%	0.0002320	0.0000017
167	95.54%	0.00009554%	0.0002336	0.0000017
168	96.18%	0.00009618%	0.0002352	0.0000016
169	96.82%	0.00009682%	0.0002367	0.0000016
170	97.45%	0.00009745%	0.0002383	0.0000016
171	98.09%	0.00009809%	0.0002398	0.0000015
172	98.73%	0.00009873%	0.0002414	0.0000015
173	99.36%	0.00009936%	0.0002429	0.0000015
174	100.00%	0.00010000%	0.0002445	0.0000014
Beyond (f)				0.0000476
Total				0.0010679

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

Year	<------------(Percentage)------------> Certain (a)	Expected (b)	<--------------(River-Mile Years)--------------> Current Value	Present Value
0	0.00%	0.00000000%	0.0000000	0.0000000
1	0.64%	0.00000064%	0.0000016	0.0000015
2	1.27%	0.00000127%	0.0000031	0.0000029
3	1.91%	0.00000191%	0.0000047	0.0000043
4	2.55%	0.00000255%	0.0000062	0.0000055
5	3.18%	0.00000318%	0.0000078	0.0000067
6	3.82%	0.00000382%	0.0000093	0.0000078
7	4.46%	0.00000446%	0.0000109	0.0000089
8	5.10%	0.00000510%	0.0000125	0.0000098
9	5.73%	0.00000573%	0.0000140	0.0000107
10	6.37%	0.00000637%	0.0000156	0.0000116
11	7.01%	0.00000701%	0.0000171	0.0000124
12	7.64%	0.00000764%	0.0000187	0.0000131
13	8.28%	0.00000828%	0.0000202	0.0000138
14	8.92%	0.00000892%	0.0000218	0.0000144
15	9.55%	0.00000955%	0.0000234	0.0000150
16	10.19%	0.00001019%	0.0000249	0.0000155
17	10.83%	0.00001083%	0.0000265	0.0000160
18	11.46%	0.00001146%	0.0000280	0.0000165
19	12.10%	0.00001210%	0.0000296	0.0000169
20	12.74%	0.00001274%	0.0000311	0.0000172
21	13.38%	0.00001338%	0.0000327	0.0000176
22	14.01%	0.00001401%	0.0000343	0.0000179
23	14.65%	0.00001465%	0.0000358	0.0000181
24	15.29%	0.00001529%	0.0000374	0.0000184
25	15.92%	0.00001592%	0.0000389	0.0000186
26	16.56%	0.00001656%	0.0000405	0.0000188
27	17.20%	0.00001720%	0.0000420	0.0000189
28	17.83%	0.00001783%	0.0000436	0.0000191
29	18.47%	0.00001847%	0.0000452	0.0000192
30	19.11%	0.00001911%	0.0000467	0.0000192
31	19.75%	0.00001975%	0.0000483	0.0000193
32	20.38%	0.00002038%	0.0000498	0.0000194
33	21.02%	0.00002102%	0.0000514	0.0000194
34	21.66%	0.00002166%	0.0000529	0.0000194
35	22.29%	0.00002229%	0.0000545	0.0000194
36	22.93%	0.00002293%	0.0000561	0.0000193
37	23.57%	0.00002357%	0.0000576	0.0000193
38	24.20%	0.00002420%	0.0000592	0.0000192
39	24.84%	0.00002484%	0.0000607	0.0000192
40	25.48%	0.00002548%	0.0000623	0.0000191
41	26.11%	0.00002611%	0.0000639	0.0000190
42	26.75%	0.00002675%	0.0000654	0.0000189

43	27.39%	0.00002739%	0.0000670	0.0000188
44	28.03%	0.00002803%	0.0000685	0.0000187
45	28.66%	0.00002866%	0.0000701	0.0000185
46	29.30%	0.00002930%	0.0000716	0.0000184
47	29.94%	0.00002994%	0.0000732	0.0000182
48	30.57%	0.00003057%	0.0000748	0.0000181
49	31.21%	0.00003121%	0.0000763	0.0000179
50	31.85%	0.00003185%	0.0000779	0.0000178
51	32.48%	0.00003248%	0.0000794	0.0000176
52	33.12%	0.00003312%	0.0000810	0.0000174
53	33.76%	0.00003376%	0.0000825	0.0000172
54	34.39%	0.00003439%	0.0000841	0.0000170
55	35.03%	0.00003503%	0.0000857	0.0000169
56	35.67%	0.00003567%	0.0000872	0.0000167
57	36.31%	0.00003631%	0.0000888	0.0000165
58	36.94%	0.00003694%	0.0000903	0.0000163
59	37.58%	0.00003758%	0.0000919	0.0000161
60	38.22%	0.00003822%	0.0000934	0.0000159
61	38.85%	0.00003885%	0.0000950	0.0000157
62	39.49%	0.00003949%	0.0000966	0.0000154
63	40.13%	0.00004013%	0.0000981	0.0000152
64	40.76%	0.00004076%	0.0000997	0.0000150
65	41.40%	0.00004140%	0.0001012	0.0000148
66	42.04%	0.00004204%	0.0001028	0.0000146
67	42.68%	0.00004268%	0.0001043	0.0000144
68	43.31%	0.00004331%	0.0001059	0.0000142
69	43.95%	0.00004395%	0.0001075	0.0000140
70	44.59%	0.00004459%	0.0001090	0.0000138
71	45.22%	0.00004522%	0.0001106	0.0000136
72	45.86%	0.00004586%	0.0001121	0.0000133
73	46.50%	0.00004650%	0.0001137	0.0000131
74	47.13%	0.00004713%	0.0001152	0.0000129
75	47.77%	0.00004777%	0.0001168	0.0000127
76	48.41%	0.00004841%	0.0001184	0.0000125
77	49.04%	0.00004904%	0.0001199	0.0000123
78	49.68%	0.00004968%	0.0001215	0.0000121
79	50.32%	0.00005032%	0.0001230	0.0000119
80	50.96%	0.00005096%	0.0001246	0.0000117
81	51.59%	0.00005159%	0.0001261	0.0000115
82	52.23%	0.00005223%	0.0001277	0.0000113
83	52.87%	0.00005287%	0.0001293	0.0000111
84	53.50%	0.00005350%	0.0001308	0.0000109
85	54.14%	0.00005414%	0.0001324	0.0000107
86	54.78%	0.00005478%	0.0001339	0.0000105
87	55.41%	0.00005541%	0.0001355	0.0000104
88	56.05%	0.00005605%	0.0001370	0.0000102
89	56.69%	0.00005669%	0.0001386	0.0000100
90	57.32%	0.00005732%	0.0001402	0.0000098
91	57.96%	0.00005796%	0.0001417	0.0000096
92	58.60%	0.00005860%	0.0001433	0.0000094
93	59.24%	0.00005924%	0.0001448	0.0000093
94	59.87%	0.00005987%	0.0001464	0.0000091

95	60.51%	0.00006051%	0.0001479	0.0000089
96	61.15%	0.00006115%	0.0001495	0.0000088
97	61.78%	0.00006178%	0.0001511	0.0000086
98	62.42%	0.00006242%	0.0001526	0.0000084
99	63.06%	0.00006306%	0.0001542	0.0000083
100	63.69%	0.00006369%	0.0001557	0.0000081
101	64.33%	0.00006433%	0.0001573	0.0000079
102	64.97%	0.00006497%	0.0001588	0.0000078
103	65.61%	0.00006561%	0.0001604	0.0000076
104	66.24%	0.00006624%	0.0001620	0.0000075
105	66.88%	0.00006688%	0.0001635	0.0000073
106	67.52%	0.00006752%	0.0001651	0.0000072
107	68.15%	0.00006815%	0.0001666	0.0000070
108	68.79%	0.00006879%	0.0001682	0.0000069
109	69.43%	0.00006943%	0.0001697	0.0000068
110	70.06%	0.00007006%	0.0001713	0.0000066
111	70.70%	0.00007070%	0.0001729	0.0000065
112	71.34%	0.00007134%	0.0001744	0.0000064
113	71.97%	0.00007197%	0.0001760	0.0000062
114	72.61%	0.00007261%	0.0001775	0.0000061
115	73.25%	0.00007325%	0.0001791	0.0000060
116	73.89%	0.00007389%	0.0001806	0.0000059
117	74.52%	0.00007452%	0.0001822	0.0000057
118	75.16%	0.00007516%	0.0001838	0.0000056
119	75.80%	0.00007580%	0.0001853	0.0000055
120	76.43%	0.00007643%	0.0001869	0.0000054
121	77.07%	0.00007707%	0.0001884	0.0000053
122	77.71%	0.00007771%	0.0001900	0.0000052
123	78.34%	0.00007834%	0.0001916	0.0000051
124	78.98%	0.00007898%	0.0001931	0.0000049
125	79.62%	0.00007962%	0.0001947	0.0000048
126	80.25%	0.00008025%	0.0001962	0.0000047
127	80.89%	0.00008089%	0.0001978	0.0000046
128	81.53%	0.00008153%	0.0001993	0.0000045
129	82.17%	0.00008217%	0.0002009	0.0000044
130	82.80%	0.00008280%	0.0002025	0.0000043
131	83.44%	0.00008344%	0.0002040	0.0000042
132	84.08%	0.00008408%	0.0002056	0.0000042
133	84.71%	0.00008471%	0.0002071	0.0000041
134	85.35%	0.00008535%	0.0002087	0.0000040
135	85.99%	0.00008599%	0.0002102	0.0000039
136	86.62%	0.00008662%	0.0002118	0.0000038
137	87.26%	0.00008726%	0.0002134	0.0000037
138	87.90%	0.00008790%	0.0002149	0.0000036
139	88.54%	0.00008854%	0.0002165	0.0000036
140	89.17%	0.00008917%	0.0002180	0.0000035
141	89.81%	0.00008981%	0.0002196	0.0000034
142	90.45%	0.00009045%	0.0002211	0.0000033
143	91.08%	0.00009108%	0.0002227	0.0000033
144	91.72%	0.00009172%	0.0002243	0.0000032
145	92.36%	0.00009236%	0.0002258	0.0000031
146	92.99%	0.00009299%	0.0002274	0.0000030

147	93.63%	0.00009363%	0.0002289	0.0000030
148	94.27%	0.00009427%	0.0002305	0.0000029
149	94.90%	0.00009490%	0.0002320	0.0000028
150	95.54%	0.00009554%	0.0002336	0.0000028
151	96.18%	0.00009618%	0.0002352	0.0000027
152	96.82%	0.00009682%	0.0002367	0.0000026
153	97.45%	0.00009745%	0.0002383	0.0000026
154	98.09%	0.00009809%	0.0002398	0.0000025
155	98.73%	0.00009873%	0.0002414	0.0000025
156	99.36%	0.00009936%	0.0002429	0.0000024
157	100.00%	0.00010000%	0.0002445	0.0000024
Beyond (g)				0.0000787
Total				0.0017651

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres): 0.00632

Lake Ashtabula - Jump Dispersal (acres): 0.00716

Lower Sheyenne River - Progressive Dispersal (river-miles):	0.0000803
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.0000485
Upper Sheyenne River - Jump Dispersal (river-miles):	0.0000801

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 175 into perpetuity

(f) From year 175 into perpetuity

(g) From year 158 into perpetuity

(h) From year 26 into perpetuity

Appendix 3D. Habitat Equivalency Analysis of Risk Consequences:
Missouri River Import to Red River Valley, Slow Invasion - Moderate Risk (One Organism)

Probability of successful invasion:	1.00E-03
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.0000	0.0000
1	5.88%	0.00588%	0.3079	0.2989
2	11.76%	0.01176%	0.6158	0.5804
3	17.65%	0.01765%	0.9236	0.8453
4	23.53%	0.02353%	1.2315	1.0942
5	29.41%	0.02941%	1.5394	1.3279
6	35.29%	0.03529%	1.8473	1.5471
7	41.18%	0.04118%	2.1552	1.7524
8	47.06%	0.04706%	2.4631	1.9444
9	52.94%	0.05294%	2.7709	2.1237
10	58.82%	0.05882%	3.0788	2.2909
11	64.71%	0.06471%	3.3867	2.4466
12	70.59%	0.07059%	3.6946	2.5913
13	76.47%	0.07647%	4.0025	2.7255
14	82.35%	0.08235%	4.3104	2.8497
15	88.24%	0.08824%	4.6182	2.9643
16	94.12%	0.09412%	4.9261	3.0698
17	100.00%	0.10000%	5.2340	3.1667
Beyond (c)				105.5552
Total				139.1741

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.0000	0.0000
1	12.50%	0.01250%	0.6543	0.6352

2	25.00%	0.02500%	1.3085	1.2334
3	37.50%	0.03750%	1.9628	1.7962
4	50.00%	0.05000%	2.6170	2.3252
5	62.50%	0.06250%	3.2713	2.8218
6	75.00%	0.07500%	3.9255	3.2875
7	87.50%	0.08750%	4.5798	3.7238
8	100.00%	0.10000%	5.2340	4.1318
Beyond (d)				137.7256
Total				157.6804

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.0000	0.0000
1	0.57%	0.00057%	0.0016	0.0015
2	1.15%	0.00115%	0.0031	0.0029
3	1.72%	0.00172%	0.0047	0.0043
4	2.30%	0.00230%	0.0062	0.0055
5	2.87%	0.00287%	0.0078	0.0067
6	3.45%	0.00345%	0.0093	0.0078
7	4.02%	0.00402%	0.0109	0.0088
8	4.60%	0.00460%	0.0124	0.0098
9	5.17%	0.00517%	0.0140	0.0107
10	5.75%	0.00575%	0.0155	0.0116
11	6.32%	0.00632%	0.0171	0.0124
12	6.90%	0.00690%	0.0187	0.0131
13	7.47%	0.00747%	0.0202	0.0138
14	8.05%	0.00805%	0.0218	0.0144
15	8.62%	0.00862%	0.0233	0.0150
16	9.20%	0.00920%	0.0249	0.0155
17	9.77%	0.00977%	0.0264	0.0160
18	10.34%	0.01034%	0.0280	0.0164
19	10.92%	0.01092%	0.0295	0.0168
20	11.49%	0.01149%	0.0311	0.0172
21	12.07%	0.01207%	0.0326	0.0175
22	12.64%	0.01264%	0.0342	0.0178
23	13.22%	0.01322%	0.0358	0.0181
24	13.79%	0.01379%	0.0373	0.0184
25	14.37%	0.01437%	0.0389	0.0186
26	14.94%	0.01494%	0.0404	0.0187
27	15.52%	0.01552%	0.0420	0.0189
28	16.09%	0.01609%	0.0435	0.0190
29	16.67%	0.01667%	0.0451	0.0191
30	17.24%	0.01724%	0.0466	0.0192
31	17.82%	0.01782%	0.0482	0.0193
32	18.39%	0.01839%	0.0497	0.0193
33	18.97%	0.01897%	0.0513	0.0193

34	19.54%	0.01954%	0.0529	0.0193
35	20.11%	0.02011%	0.0544	0.0193
36	20.69%	0.02069%	0.0560	0.0193
37	21.26%	0.02126%	0.0575	0.0193
38	21.84%	0.02184%	0.0591	0.0192
39	22.41%	0.02241%	0.0606	0.0191
40	22.99%	0.02299%	0.0622	0.0191
41	23.56%	0.02356%	0.0637	0.0190
42	24.14%	0.02414%	0.0653	0.0189
43	24.71%	0.02471%	0.0668	0.0188
44	25.29%	0.02529%	0.0684	0.0186
45	25.86%	0.02586%	0.0700	0.0185
46	26.44%	0.02644%	0.0715	0.0184
47	27.01%	0.02701%	0.0731	0.0182
48	27.59%	0.02759%	0.0746	0.0181
49	28.16%	0.02816%	0.0762	0.0179
50	28.74%	0.02874%	0.0777	0.0177
51	29.31%	0.02931%	0.0793	0.0176
52	29.89%	0.02989%	0.0808	0.0174
53	30.46%	0.03046%	0.0824	0.0172
54	31.03%	0.03103%	0.0839	0.0170
55	31.61%	0.03161%	0.0855	0.0168
56	32.18%	0.03218%	0.0871	0.0166
57	32.76%	0.03276%	0.0886	0.0164
58	33.33%	0.03333%	0.0902	0.0162
59	33.91%	0.03391%	0.0917	0.0160
60	34.48%	0.03448%	0.0933	0.0158
61	35.06%	0.03506%	0.0948	0.0156
62	35.63%	0.03563%	0.0964	0.0154
63	36.21%	0.03621%	0.0979	0.0152
64	36.78%	0.03678%	0.0995	0.0150
65	37.36%	0.03736%	0.1010	0.0148
66	37.93%	0.03793%	0.1026	0.0146
67	38.51%	0.03851%	0.1042	0.0144
68	39.08%	0.03908%	0.1057	0.0142
69	39.66%	0.03966%	0.1073	0.0140
70	40.23%	0.04023%	0.1088	0.0137
71	40.80%	0.04080%	0.1104	0.0135
72	41.38%	0.04138%	0.1119	0.0133
73	41.95%	0.04195%	0.1135	0.0131
74	42.53%	0.04253%	0.1150	0.0129
75	43.10%	0.04310%	0.1166	0.0127
76	43.68%	0.04368%	0.1181	0.0125
77	44.25%	0.04425%	0.1197	0.0123
78	44.83%	0.04483%	0.1213	0.0121
79	45.40%	0.04540%	0.1228	0.0119
80	45.98%	0.04598%	0.1244	0.0117
81	46.55%	0.04655%	0.1259	0.0115
82	47.13%	0.04713%	0.1275	0.0113
83	47.70%	0.04770%	0.1290	0.0111
84	48.28%	0.04828%	0.1306	0.0109
85	48.85%	0.04885%	0.1321	0.0107

86	49.43%	0.04943%	0.1337	0.0105
87	50.00%	0.05000%	0.1353	0.0103
88	50.57%	0.05057%	0.1368	0.0101
89	51.15%	0.05115%	0.1384	0.0100
90	51.72%	0.05172%	0.1399	0.0098
91	52.30%	0.05230%	0.1415	0.0096
92	52.87%	0.05287%	0.1430	0.0094
93	53.45%	0.05345%	0.1446	0.0093
94	54.02%	0.05402%	0.1461	0.0091
95	54.60%	0.05460%	0.1477	0.0089
96	55.17%	0.05517%	0.1492	0.0087
97	55.75%	0.05575%	0.1508	0.0086
98	56.32%	0.05632%	0.1524	0.0084
99	56.90%	0.05690%	0.1539	0.0082
100	57.47%	0.05747%	0.1555	0.0081
101	58.05%	0.05805%	0.1570	0.0079
102	58.62%	0.05862%	0.1586	0.0078
103	59.20%	0.05920%	0.1601	0.0076
104	59.77%	0.05977%	0.1617	0.0075
105	60.34%	0.06034%	0.1632	0.0073
106	60.92%	0.06092%	0.1648	0.0072
107	61.49%	0.06149%	0.1663	0.0070
108	62.07%	0.06207%	0.1679	0.0069
109	62.64%	0.06264%	0.1695	0.0068
110	63.22%	0.06322%	0.1710	0.0066
111	63.79%	0.06379%	0.1726	0.0065
112	64.37%	0.06437%	0.1741	0.0064
113	64.94%	0.06494%	0.1757	0.0062
114	65.52%	0.06552%	0.1772	0.0061
115	66.09%	0.06609%	0.1788	0.0060
116	66.67%	0.06667%	0.1803	0.0058
117	67.24%	0.06724%	0.1819	0.0057
118	67.82%	0.06782%	0.1834	0.0056
119	68.39%	0.06839%	0.1850	0.0055
120	68.97%	0.06897%	0.1866	0.0054
121	69.54%	0.06954%	0.1881	0.0053
122	70.11%	0.07011%	0.1897	0.0052
123	70.69%	0.07069%	0.1912	0.0050
124	71.26%	0.07126%	0.1928	0.0049
125	71.84%	0.07184%	0.1943	0.0048
126	72.41%	0.07241%	0.1959	0.0047
127	72.99%	0.07299%	0.1974	0.0046
128	73.56%	0.07356%	0.1990	0.0045
129	74.14%	0.07414%	0.2005	0.0044
130	74.71%	0.07471%	0.2021	0.0043
131	75.29%	0.07529%	0.2037	0.0042
132	75.86%	0.07586%	0.2052	0.0041
133	76.44%	0.07644%	0.2068	0.0041
134	77.01%	0.07701%	0.2083	0.0040
135	77.59%	0.07759%	0.2099	0.0039
136	78.16%	0.07816%	0.2114	0.0038
137	78.74%	0.07874%	0.2130	0.0037

138	79.31%	0.07931%	0.2145	0.0036
139	79.89%	0.07989%	0.2161	0.0036
140	80.46%	0.08046%	0.2176	0.0035
141	81.03%	0.08103%	0.2192	0.0034
142	81.61%	0.08161%	0.2208	0.0033
143	82.18%	0.08218%	0.2223	0.0032
144	82.76%	0.08276%	0.2239	0.0032
145	83.33%	0.08333%	0.2254	0.0031
146	83.91%	0.08391%	0.2270	0.0030
147	84.48%	0.08448%	0.2285	0.0030
148	85.06%	0.08506%	0.2301	0.0029
149	85.63%	0.08563%	0.2316	0.0028
150	86.21%	0.08621%	0.2332	0.0028
151	86.78%	0.08678%	0.2347	0.0027
152	87.36%	0.08736%	0.2363	0.0026
153	87.93%	0.08793%	0.2379	0.0026
154	88.51%	0.08851%	0.2394	0.0025
155	89.08%	0.08908%	0.2410	0.0025
156	89.66%	0.08966%	0.2425	0.0024
157	90.23%	0.09023%	0.2441	0.0024
158	90.80%	0.09080%	0.2456	0.0023
159	91.38%	0.09138%	0.2472	0.0022
160	91.95%	0.09195%	0.2487	0.0022
161	92.53%	0.09253%	0.2503	0.0021
162	93.10%	0.09310%	0.2518	0.0021
163	93.68%	0.09368%	0.2534	0.0020
164	94.25%	0.09425%	0.2550	0.0020
165	94.83%	0.09483%	0.2565	0.0020
166	95.40%	0.09540%	0.2581	0.0019
167	95.98%	0.09598%	0.2596	0.0019
168	96.55%	0.09655%	0.2612	0.0018
169	97.13%	0.09713%	0.2627	0.0018
170	97.70%	0.09770%	0.2643	0.0017
171	98.28%	0.09828%	0.2658	0.0017
172	98.85%	0.09885%	0.2674	0.0017
173	99.43%	0.09943%	0.2689	0.0016
174	100.00%	0.10000%	0.2705	0.0016
Beyond (e)				0.0526
Total				1.7688

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.00000%	0.0000	0.0000
18	0.64%	0.00064%	0.0016	0.0009
19	1.27%	0.00127%	0.0031	0.0018
20	1.91%	0.00191%	0.0047	0.0026

21	2.55%	0.00255%	0.0062	0.0033
22	3.18%	0.00318%	0.0078	0.0041
23	3.82%	0.00382%	0.0093	0.0047
24	4.46%	0.00446%	0.0109	0.0054
25	5.10%	0.00510%	0.0125	0.0060
26	5.73%	0.00573%	0.0140	0.0065
27	6.37%	0.00637%	0.0156	0.0070
28	7.01%	0.00701%	0.0171	0.0075
29	7.64%	0.00764%	0.0187	0.0079
30	8.28%	0.00828%	0.0202	0.0083
31	8.92%	0.00892%	0.0218	0.0087
32	9.55%	0.00955%	0.0234	0.0091
33	10.19%	0.01019%	0.0249	0.0094
34	10.83%	0.01083%	0.0265	0.0097
35	11.46%	0.01146%	0.0280	0.0100
36	12.10%	0.01210%	0.0296	0.0102
37	12.74%	0.01274%	0.0311	0.0104
38	13.38%	0.01338%	0.0327	0.0106
39	14.01%	0.01401%	0.0343	0.0108
40	14.65%	0.01465%	0.0358	0.0110
41	15.29%	0.01529%	0.0374	0.0111
42	15.92%	0.01592%	0.0389	0.0113
43	16.56%	0.01656%	0.0405	0.0114
44	17.20%	0.01720%	0.0420	0.0115
45	17.83%	0.01783%	0.0436	0.0115
46	18.47%	0.01847%	0.0452	0.0116
47	19.11%	0.01911%	0.0467	0.0116
48	19.75%	0.01975%	0.0483	0.0117
49	20.38%	0.02038%	0.0498	0.0117
50	21.02%	0.02102%	0.0514	0.0117
51	21.66%	0.02166%	0.0529	0.0117
52	22.29%	0.02229%	0.0545	0.0117
53	22.93%	0.02293%	0.0561	0.0117
54	23.57%	0.02357%	0.0576	0.0117
55	24.20%	0.02420%	0.0592	0.0116
56	24.84%	0.02484%	0.0607	0.0116
57	25.48%	0.02548%	0.0623	0.0116
58	26.11%	0.02611%	0.0639	0.0115
59	26.75%	0.02675%	0.0654	0.0114
60	27.39%	0.02739%	0.0670	0.0114
61	28.03%	0.02803%	0.0685	0.0113
62	28.66%	0.02866%	0.0701	0.0112
63	29.30%	0.02930%	0.0716	0.0111
64	29.94%	0.02994%	0.0732	0.0110
65	30.57%	0.03057%	0.0748	0.0109
66	31.21%	0.03121%	0.0763	0.0108
67	31.85%	0.03185%	0.0779	0.0107
68	32.48%	0.03248%	0.0794	0.0106
69	33.12%	0.03312%	0.0810	0.0105
70	33.76%	0.03376%	0.0825	0.0104
71	34.39%	0.03439%	0.0841	0.0103
72	35.03%	0.03503%	0.0857	0.0102

73	35.67%	0.03567%	0.0872	0.0101
74	36.31%	0.03631%	0.0888	0.0100
75	36.94%	0.03694%	0.0903	0.0098
76	37.58%	0.03758%	0.0919	0.0097
77	38.22%	0.03822%	0.0934	0.0096
78	38.85%	0.03885%	0.0950	0.0095
79	39.49%	0.03949%	0.0966	0.0093
80	40.13%	0.04013%	0.0981	0.0092
81	40.76%	0.04076%	0.0997	0.0091
82	41.40%	0.04140%	0.1012	0.0090
83	42.04%	0.04204%	0.1028	0.0088
84	42.68%	0.04268%	0.1043	0.0087
85	43.31%	0.04331%	0.1059	0.0086
86	43.95%	0.04395%	0.1075	0.0085
87	44.59%	0.04459%	0.1090	0.0083
88	45.22%	0.04522%	0.1106	0.0082
89	45.86%	0.04586%	0.1121	0.0081
90	46.50%	0.04650%	0.1137	0.0079
91	47.13%	0.04713%	0.1152	0.0078
92	47.77%	0.04777%	0.1168	0.0077
93	48.41%	0.04841%	0.1184	0.0076
94	49.04%	0.04904%	0.1199	0.0075
95	49.68%	0.04968%	0.1215	0.0073
96	50.32%	0.05032%	0.1230	0.0072
97	50.96%	0.05096%	0.1246	0.0071
98	51.59%	0.05159%	0.1261	0.0070
99	52.23%	0.05223%	0.1277	0.0068
100	52.87%	0.05287%	0.1293	0.0067
101	53.50%	0.05350%	0.1308	0.0066
102	54.14%	0.05414%	0.1324	0.0065
103	54.78%	0.05478%	0.1339	0.0064
104	55.41%	0.05541%	0.1355	0.0063
105	56.05%	0.05605%	0.1370	0.0062
106	56.69%	0.05669%	0.1386	0.0060
107	57.32%	0.05732%	0.1402	0.0059
108	57.96%	0.05796%	0.1417	0.0058
109	58.60%	0.05860%	0.1433	0.0057
110	59.24%	0.05924%	0.1448	0.0056
111	59.87%	0.05987%	0.1464	0.0055
112	60.51%	0.06051%	0.1479	0.0054
113	61.15%	0.06115%	0.1495	0.0053
114	61.78%	0.06178%	0.1511	0.0052
115	62.42%	0.06242%	0.1526	0.0051
116	63.06%	0.06306%	0.1542	0.0050
117	63.69%	0.06369%	0.1557	0.0049
118	64.33%	0.06433%	0.1573	0.0048
119	64.97%	0.06497%	0.1588	0.0047
120	65.61%	0.06561%	0.1604	0.0046
121	66.24%	0.06624%	0.1620	0.0045
122	66.88%	0.06688%	0.1635	0.0044
123	67.52%	0.06752%	0.1651	0.0044
124	68.15%	0.06815%	0.1666	0.0043

125	68.79%	0.06879%	0.1682	0.0042
126	69.43%	0.06943%	0.1697	0.0041
127	70.06%	0.07006%	0.1713	0.0040
128	70.70%	0.07070%	0.1729	0.0039
129	71.34%	0.07134%	0.1744	0.0039
130	71.97%	0.07197%	0.1760	0.0038
131	72.61%	0.07261%	0.1775	0.0037
132	73.25%	0.07325%	0.1791	0.0036
133	73.89%	0.07389%	0.1806	0.0035
134	74.52%	0.07452%	0.1822	0.0035
135	75.16%	0.07516%	0.1838	0.0034
136	75.80%	0.07580%	0.1853	0.0033
137	76.43%	0.07643%	0.1869	0.0033
138	77.07%	0.07707%	0.1884	0.0032
139	77.71%	0.07771%	0.1900	0.0031
140	78.34%	0.07834%	0.1916	0.0031
141	78.98%	0.07898%	0.1931	0.0030
142	79.62%	0.07962%	0.1947	0.0029
143	80.25%	0.08025%	0.1962	0.0029
144	80.89%	0.08089%	0.1978	0.0028
145	81.53%	0.08153%	0.1993	0.0027
146	82.17%	0.08217%	0.2009	0.0027
147	82.80%	0.08280%	0.2025	0.0026
148	83.44%	0.08344%	0.2040	0.0026
149	84.08%	0.08408%	0.2056	0.0025
150	84.71%	0.08471%	0.2071	0.0025
151	85.35%	0.08535%	0.2087	0.0024
152	85.99%	0.08599%	0.2102	0.0024
153	86.62%	0.08662%	0.2118	0.0023
154	87.26%	0.08726%	0.2134	0.0022
155	87.90%	0.08790%	0.2149	0.0022
156	88.54%	0.08854%	0.2165	0.0022
157	89.17%	0.08917%	0.2180	0.0021
158	89.81%	0.08981%	0.2196	0.0021
159	90.45%	0.09045%	0.2211	0.0020
160	91.08%	0.09108%	0.2227	0.0020
161	91.72%	0.09172%	0.2243	0.0019
162	92.36%	0.09236%	0.2258	0.0019
163	92.99%	0.09299%	0.2274	0.0018
164	93.63%	0.09363%	0.2289	0.0018
165	94.27%	0.09427%	0.2305	0.0018
166	94.90%	0.09490%	0.2320	0.0017
167	95.54%	0.09554%	0.2336	0.0017
168	96.18%	0.09618%	0.2352	0.0016
169	96.82%	0.09682%	0.2367	0.0016
170	97.45%	0.09745%	0.2383	0.0016
171	98.09%	0.09809%	0.2398	0.0015
172	98.73%	0.09873%	0.2414	0.0015
173	99.36%	0.09936%	0.2429	0.0015
174	100.00%	0.10000%	0.2445	0.0014
Beyond (f)				0.0476
Total				1.0679

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.0000	0.0000
1	0.64%	0.00064%	0.0016	0.0015
2	1.27%	0.00127%	0.0031	0.0029
3	1.91%	0.00191%	0.0047	0.0043
4	2.55%	0.00255%	0.0062	0.0055
5	3.18%	0.00318%	0.0078	0.0067
6	3.82%	0.00382%	0.0093	0.0078
7	4.46%	0.00446%	0.0109	0.0089
8	5.10%	0.00510%	0.0125	0.0098
9	5.73%	0.00573%	0.0140	0.0107
10	6.37%	0.00637%	0.0156	0.0116
11	7.01%	0.00701%	0.0171	0.0124
12	7.64%	0.00764%	0.0187	0.0131
13	8.28%	0.00828%	0.0202	0.0138
14	8.92%	0.00892%	0.0218	0.0144
15	9.55%	0.00955%	0.0234	0.0150
16	10.19%	0.01019%	0.0249	0.0155
17	10.83%	0.01083%	0.0265	0.0160
18	11.46%	0.01146%	0.0280	0.0165
19	12.10%	0.01210%	0.0296	0.0169
20	12.74%	0.01274%	0.0311	0.0172
21	13.38%	0.01338%	0.0327	0.0176
22	14.01%	0.01401%	0.0343	0.0179
23	14.65%	0.01465%	0.0358	0.0181
24	15.29%	0.01529%	0.0374	0.0184
25	15.92%	0.01592%	0.0389	0.0186
26	16.56%	0.01656%	0.0405	0.0188
27	17.20%	0.01720%	0.0420	0.0189
28	17.83%	0.01783%	0.0436	0.0191
29	18.47%	0.01847%	0.0452	0.0192
30	19.11%	0.01911%	0.0467	0.0192
31	19.75%	0.01975%	0.0483	0.0193
32	20.38%	0.02038%	0.0498	0.0194
33	21.02%	0.02102%	0.0514	0.0194
34	21.66%	0.02166%	0.0529	0.0194
35	22.29%	0.02229%	0.0545	0.0194
36	22.93%	0.02293%	0.0561	0.0193
37	23.57%	0.02357%	0.0576	0.0193
38	24.20%	0.02420%	0.0592	0.0192
39	24.84%	0.02484%	0.0607	0.0192
40	25.48%	0.02548%	0.0623	0.0191
41	26.11%	0.02611%	0.0639	0.0190
42	26.75%	0.02675%	0.0654	0.0189

43	27.39%	0.02739%	0.0670	0.0188
44	28.03%	0.02803%	0.0685	0.0187
45	28.66%	0.02866%	0.0701	0.0185
46	29.30%	0.02930%	0.0716	0.0184
47	29.94%	0.02994%	0.0732	0.0182
48	30.57%	0.03057%	0.0748	0.0181
49	31.21%	0.03121%	0.0763	0.0179
50	31.85%	0.03185%	0.0779	0.0178
51	32.48%	0.03248%	0.0794	0.0176
52	33.12%	0.03312%	0.0810	0.0174
53	33.76%	0.03376%	0.0825	0.0172
54	34.39%	0.03439%	0.0841	0.0170
55	35.03%	0.03503%	0.0857	0.0169
56	35.67%	0.03567%	0.0872	0.0167
57	36.31%	0.03631%	0.0888	0.0165
58	36.94%	0.03694%	0.0903	0.0163
59	37.58%	0.03758%	0.0919	0.0161
60	38.22%	0.03822%	0.0934	0.0159
61	38.85%	0.03885%	0.0950	0.0157
62	39.49%	0.03949%	0.0966	0.0154
63	40.13%	0.04013%	0.0981	0.0152
64	40.76%	0.04076%	0.0997	0.0150
65	41.40%	0.04140%	0.1012	0.0148
66	42.04%	0.04204%	0.1028	0.0146
67	42.68%	0.04268%	0.1043	0.0144
68	43.31%	0.04331%	0.1059	0.0142
69	43.95%	0.04395%	0.1075	0.0140
70	44.59%	0.04459%	0.1090	0.0138
71	45.22%	0.04522%	0.1106	0.0136
72	45.86%	0.04586%	0.1121	0.0133
73	46.50%	0.04650%	0.1137	0.0131
74	47.13%	0.04713%	0.1152	0.0129
75	47.77%	0.04777%	0.1168	0.0127
76	48.41%	0.04841%	0.1184	0.0125
77	49.04%	0.04904%	0.1199	0.0123
78	49.68%	0.04968%	0.1215	0.0121
79	50.32%	0.05032%	0.1230	0.0119
80	50.96%	0.05096%	0.1246	0.0117
81	51.59%	0.05159%	0.1261	0.0115
82	52.23%	0.05223%	0.1277	0.0113
83	52.87%	0.05287%	0.1293	0.0111
84	53.50%	0.05350%	0.1308	0.0109
85	54.14%	0.05414%	0.1324	0.0107
86	54.78%	0.05478%	0.1339	0.0105
87	55.41%	0.05541%	0.1355	0.0104
88	56.05%	0.05605%	0.1370	0.0102
89	56.69%	0.05669%	0.1386	0.0100
90	57.32%	0.05732%	0.1402	0.0098
91	57.96%	0.05796%	0.1417	0.0096
92	58.60%	0.05860%	0.1433	0.0094
93	59.24%	0.05924%	0.1448	0.0093
94	59.87%	0.05987%	0.1464	0.0091

95	60.51%	0.06051%	0.1479	0.0089
96	61.15%	0.06115%	0.1495	0.0088
97	61.78%	0.06178%	0.1511	0.0086
98	62.42%	0.06242%	0.1526	0.0084
99	63.06%	0.06306%	0.1542	0.0083
100	63.69%	0.06369%	0.1557	0.0081
101	64.33%	0.06433%	0.1573	0.0079
102	64.97%	0.06497%	0.1588	0.0078
103	65.61%	0.06561%	0.1604	0.0076
104	66.24%	0.06624%	0.1620	0.0075
105	66.88%	0.06688%	0.1635	0.0073
106	67.52%	0.06752%	0.1651	0.0072
107	68.15%	0.06815%	0.1666	0.0070
108	68.79%	0.06879%	0.1682	0.0069
109	69.43%	0.06943%	0.1697	0.0068
110	70.06%	0.07006%	0.1713	0.0066
111	70.70%	0.07070%	0.1729	0.0065
112	71.34%	0.07134%	0.1744	0.0064
113	71.97%	0.07197%	0.1760	0.0062
114	72.61%	0.07261%	0.1775	0.0061
115	73.25%	0.07325%	0.1791	0.0060
116	73.89%	0.07389%	0.1806	0.0059
117	74.52%	0.07452%	0.1822	0.0057
118	75.16%	0.07516%	0.1838	0.0056
119	75.80%	0.07580%	0.1853	0.0055
120	76.43%	0.07643%	0.1869	0.0054
121	77.07%	0.07707%	0.1884	0.0053
122	77.71%	0.07771%	0.1900	0.0052
123	78.34%	0.07834%	0.1916	0.0051
124	78.98%	0.07898%	0.1931	0.0049
125	79.62%	0.07962%	0.1947	0.0048
126	80.25%	0.08025%	0.1962	0.0047
127	80.89%	0.08089%	0.1978	0.0046
128	81.53%	0.08153%	0.1993	0.0045
129	82.17%	0.08217%	0.2009	0.0044
130	82.80%	0.08280%	0.2025	0.0043
131	83.44%	0.08344%	0.2040	0.0042
132	84.08%	0.08408%	0.2056	0.0042
133	84.71%	0.08471%	0.2071	0.0041
134	85.35%	0.08535%	0.2087	0.0040
135	85.99%	0.08599%	0.2102	0.0039
136	86.62%	0.08662%	0.2118	0.0038
137	87.26%	0.08726%	0.2134	0.0037
138	87.90%	0.08790%	0.2149	0.0036
139	88.54%	0.08854%	0.2165	0.0036
140	89.17%	0.08917%	0.2180	0.0035
141	89.81%	0.08981%	0.2196	0.0034
142	90.45%	0.09045%	0.2211	0.0033
143	91.08%	0.09108%	0.2227	0.0033
144	91.72%	0.09172%	0.2243	0.0032
145	92.36%	0.09236%	0.2258	0.0031
146	92.99%	0.09299%	0.2274	0.0030

147	93.63%	0.09363%	0.2289	0.0030
148	94.27%	0.09427%	0.2305	0.0029
149	94.90%	0.09490%	0.2320	0.0028
150	95.54%	0.09554%	0.2336	0.0028
151	96.18%	0.09618%	0.2352	0.0027
152	96.82%	0.09682%	0.2367	0.0026
153	97.45%	0.09745%	0.2383	0.0026
154	98.09%	0.09809%	0.2398	0.0025
155	98.73%	0.09873%	0.2414	0.0025
156	99.36%	0.09936%	0.2429	0.0024
157	100.00%	0.10000%	0.2445	0.0024
Beyond (g)				0.0787
Total				1.7651

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres): 6.32

Lake Ashtabula - Jump Dispersal (acres): 7.16

Lower Sheyenne River - Progressive Dispersal (river-miles):	0.0803
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.0485
Upper Sheyenne River - Jump Dispersal (river-miles):	0.0801

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 175 into perpetuity

(f) From year 175 into perpetuity

(g) From year 158 into perpetuity

(h) From year 26 into perpetuity

Appendix 3E. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Slow Invasion - High Risk (One Organism)

Probability of successful invasion:	1.00E-02
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.000	0.000
1	5.88%	0.0588%	3.079	2.989
2	11.76%	0.1176%	6.158	5.804
3	17.65%	0.1765%	9.236	8.453
4	23.53%	0.2353%	12.315	10.942
5	29.41%	0.2941%	15.394	13.279
6	35.29%	0.3529%	18.473	15.471
7	41.18%	0.4118%	21.552	17.524
8	47.06%	0.4706%	24.631	19.444
9	52.94%	0.5294%	27.709	21.237
10	58.82%	0.5882%	30.788	22.909
11	64.71%	0.6471%	33.867	24.466
12	70.59%	0.7059%	36.946	25.913
13	76.47%	0.7647%	40.025	27.255
14	82.35%	0.8235%	43.104	28.497
15	88.24%	0.8824%	46.182	29.643
16	94.12%	0.9412%	49.261	30.698
17	100.00%	1.0000%	52.340	31.667
Beyond (c)				1,055.552
Total				1,391.741

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.000	0.000
1	12.50%	0.1250%	6.543	6.352

2	25.00%	0.2500%	13.085	12.334
3	37.50%	0.3750%	19.628	17.962
4	50.00%	0.5000%	26.170	23.252
5	62.50%	0.6250%	32.713	28.218
6	75.00%	0.7500%	39.255	32.875
7	87.50%	0.8750%	45.798	37.238
8	100.00%	1.0000%	52.340	41.318
Beyond (d)				1,377.256
Total				1,576.804

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.000	0.000
1	0.57%	0.0057%	0.016	0.015
2	1.15%	0.0115%	0.031	0.029
3	1.72%	0.0172%	0.047	0.043
4	2.30%	0.0230%	0.062	0.055
5	2.87%	0.0287%	0.078	0.067
6	3.45%	0.0345%	0.093	0.078
7	4.02%	0.0402%	0.109	0.088
8	4.60%	0.0460%	0.124	0.098
9	5.17%	0.0517%	0.140	0.107
10	5.75%	0.0575%	0.155	0.116
11	6.32%	0.0632%	0.171	0.124
12	6.90%	0.0690%	0.187	0.131
13	7.47%	0.0747%	0.202	0.138
14	8.05%	0.0805%	0.218	0.144
15	8.62%	0.0862%	0.233	0.150
16	9.20%	0.0920%	0.249	0.155
17	9.77%	0.0977%	0.264	0.160
18	10.34%	0.1034%	0.280	0.164
19	10.92%	0.1092%	0.295	0.168
20	11.49%	0.1149%	0.311	0.172
21	12.07%	0.1207%	0.326	0.175
22	12.64%	0.1264%	0.342	0.178
23	13.22%	0.1322%	0.358	0.181
24	13.79%	0.1379%	0.373	0.184
25	14.37%	0.1437%	0.389	0.186
26	14.94%	0.1494%	0.404	0.187
27	15.52%	0.1552%	0.420	0.189
28	16.09%	0.1609%	0.435	0.190
29	16.67%	0.1667%	0.451	0.191
30	17.24%	0.1724%	0.466	0.192
31	17.82%	0.1782%	0.482	0.193
32	18.39%	0.1839%	0.497	0.193
33	18.97%	0.1897%	0.513	0.193

34	19.54%	0.1954%	0.529	0.193
35	20.11%	0.2011%	0.544	0.193
36	20.69%	0.2069%	0.560	0.193
37	21.26%	0.2126%	0.575	0.193
38	21.84%	0.2184%	0.591	0.192
39	22.41%	0.2241%	0.606	0.191
40	22.99%	0.2299%	0.622	0.191
41	23.56%	0.2356%	0.637	0.190
42	24.14%	0.2414%	0.653	0.189
43	24.71%	0.2471%	0.668	0.188
44	25.29%	0.2529%	0.684	0.186
45	25.86%	0.2586%	0.700	0.185
46	26.44%	0.2644%	0.715	0.184
47	27.01%	0.2701%	0.731	0.182
48	27.59%	0.2759%	0.746	0.181
49	28.16%	0.2816%	0.762	0.179
50	28.74%	0.2874%	0.777	0.177
51	29.31%	0.2931%	0.793	0.176
52	29.89%	0.2989%	0.808	0.174
53	30.46%	0.3046%	0.824	0.172
54	31.03%	0.3103%	0.839	0.170
55	31.61%	0.3161%	0.855	0.168
56	32.18%	0.3218%	0.871	0.166
57	32.76%	0.3276%	0.886	0.164
58	33.33%	0.3333%	0.902	0.162
59	33.91%	0.3391%	0.917	0.160
60	34.48%	0.3448%	0.933	0.158
61	35.06%	0.3506%	0.948	0.156
62	35.63%	0.3563%	0.964	0.154
63	36.21%	0.3621%	0.979	0.152
64	36.78%	0.3678%	0.995	0.150
65	37.36%	0.3736%	1.010	0.148
66	37.93%	0.3793%	1.026	0.146
67	38.51%	0.3851%	1.042	0.144
68	39.08%	0.3908%	1.057	0.142
69	39.66%	0.3966%	1.073	0.140
70	40.23%	0.4023%	1.088	0.137
71	40.80%	0.4080%	1.104	0.135
72	41.38%	0.4138%	1.119	0.133
73	41.95%	0.4195%	1.135	0.131
74	42.53%	0.4253%	1.150	0.129
75	43.10%	0.4310%	1.166	0.127
76	43.68%	0.4368%	1.181	0.125
77	44.25%	0.4425%	1.197	0.123
78	44.83%	0.4483%	1.213	0.121
79	45.40%	0.4540%	1.228	0.119
80	45.98%	0.4598%	1.244	0.117
81	46.55%	0.4655%	1.259	0.115
82	47.13%	0.4713%	1.275	0.113
83	47.70%	0.4770%	1.290	0.111
84	48.28%	0.4828%	1.306	0.109
85	48.85%	0.4885%	1.321	0.107

86	49.43%	0.4943%	1.337	0.105
87	50.00%	0.5000%	1.353	0.103
88	50.57%	0.5057%	1.368	0.101
89	51.15%	0.5115%	1.384	0.100
90	51.72%	0.5172%	1.399	0.098
91	52.30%	0.5230%	1.415	0.096
92	52.87%	0.5287%	1.430	0.094
93	53.45%	0.5345%	1.446	0.093
94	54.02%	0.5402%	1.461	0.091
95	54.60%	0.5460%	1.477	0.089
96	55.17%	0.5517%	1.492	0.087
97	55.75%	0.5575%	1.508	0.086
98	56.32%	0.5632%	1.524	0.084
99	56.90%	0.5690%	1.539	0.082
100	57.47%	0.5747%	1.555	0.081
101	58.05%	0.5805%	1.570	0.079
102	58.62%	0.5862%	1.586	0.078
103	59.20%	0.5920%	1.601	0.076
104	59.77%	0.5977%	1.617	0.075
105	60.34%	0.6034%	1.632	0.073
106	60.92%	0.6092%	1.648	0.072
107	61.49%	0.6149%	1.663	0.070
108	62.07%	0.6207%	1.679	0.069
109	62.64%	0.6264%	1.695	0.068
110	63.22%	0.6322%	1.710	0.066
111	63.79%	0.6379%	1.726	0.065
112	64.37%	0.6437%	1.741	0.064
113	64.94%	0.6494%	1.757	0.062
114	65.52%	0.6552%	1.772	0.061
115	66.09%	0.6609%	1.788	0.060
116	66.67%	0.6667%	1.803	0.058
117	67.24%	0.6724%	1.819	0.057
118	67.82%	0.6782%	1.834	0.056
119	68.39%	0.6839%	1.850	0.055
120	68.97%	0.6897%	1.866	0.054
121	69.54%	0.6954%	1.881	0.053
122	70.11%	0.7011%	1.897	0.052
123	70.69%	0.7069%	1.912	0.050
124	71.26%	0.7126%	1.928	0.049
125	71.84%	0.7184%	1.943	0.048
126	72.41%	0.7241%	1.959	0.047
127	72.99%	0.7299%	1.974	0.046
128	73.56%	0.7356%	1.990	0.045
129	74.14%	0.7414%	2.005	0.044
130	74.71%	0.7471%	2.021	0.043
131	75.29%	0.7529%	2.037	0.042
132	75.86%	0.7586%	2.052	0.041
133	76.44%	0.7644%	2.068	0.041
134	77.01%	0.7701%	2.083	0.040
135	77.59%	0.7759%	2.099	0.039
136	78.16%	0.7816%	2.114	0.038
137	78.74%	0.7874%	2.130	0.037

138	79.31%	0.7931%	2.145	0.036
139	79.89%	0.7989%	2.161	0.036
140	80.46%	0.8046%	2.176	0.035
141	81.03%	0.8103%	2.192	0.034
142	81.61%	0.8161%	2.208	0.033
143	82.18%	0.8218%	2.223	0.032
144	82.76%	0.8276%	2.239	0.032
145	83.33%	0.8333%	2.254	0.031
146	83.91%	0.8391%	2.270	0.030
147	84.48%	0.8448%	2.285	0.030
148	85.06%	0.8506%	2.301	0.029
149	85.63%	0.8563%	2.316	0.028
150	86.21%	0.8621%	2.332	0.028
151	86.78%	0.8678%	2.347	0.027
152	87.36%	0.8736%	2.363	0.026
153	87.93%	0.8793%	2.379	0.026
154	88.51%	0.8851%	2.394	0.025
155	89.08%	0.8908%	2.410	0.025
156	89.66%	0.8966%	2.425	0.024
157	90.23%	0.9023%	2.441	0.024
158	90.80%	0.9080%	2.456	0.023
159	91.38%	0.9138%	2.472	0.022
160	91.95%	0.9195%	2.487	0.022
161	92.53%	0.9253%	2.503	0.021
162	93.10%	0.9310%	2.518	0.021
163	93.68%	0.9368%	2.534	0.020
164	94.25%	0.9425%	2.550	0.020
165	94.83%	0.9483%	2.565	0.020
166	95.40%	0.9540%	2.581	0.019
167	95.98%	0.9598%	2.596	0.019
168	96.55%	0.9655%	2.612	0.018
169	97.13%	0.9713%	2.627	0.018
170	97.70%	0.9770%	2.643	0.017
171	98.28%	0.9828%	2.658	0.017
172	98.85%	0.9885%	2.674	0.017
173	99.43%	0.9943%	2.689	0.016
174	100.00%	1.0000%	2.705	0.016
Beyond (e)				0.526
Total				17.688

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.0000%	0.000	0.000
18	0.64%	0.0064%	0.016	0.009
19	1.27%	0.0127%	0.031	0.018
20	1.91%	0.0191%	0.047	0.026

21	2.55%	0.0255%	0.062	0.033
22	3.18%	0.0318%	0.078	0.041
23	3.82%	0.0382%	0.093	0.047
24	4.46%	0.0446%	0.109	0.054
25	5.10%	0.0510%	0.125	0.060
26	5.73%	0.0573%	0.140	0.065
27	6.37%	0.0637%	0.156	0.070
28	7.01%	0.0701%	0.171	0.075
29	7.64%	0.0764%	0.187	0.079
30	8.28%	0.0828%	0.202	0.083
31	8.92%	0.0892%	0.218	0.087
32	9.55%	0.0955%	0.234	0.091
33	10.19%	0.1019%	0.249	0.094
34	10.83%	0.1083%	0.265	0.097
35	11.46%	0.1146%	0.280	0.100
36	12.10%	0.1210%	0.296	0.102
37	12.74%	0.1274%	0.311	0.104
38	13.38%	0.1338%	0.327	0.106
39	14.01%	0.1401%	0.343	0.108
40	14.65%	0.1465%	0.358	0.110
41	15.29%	0.1529%	0.374	0.111
42	15.92%	0.1592%	0.389	0.113
43	16.56%	0.1656%	0.405	0.114
44	17.20%	0.1720%	0.420	0.115
45	17.83%	0.1783%	0.436	0.115
46	18.47%	0.1847%	0.452	0.116
47	19.11%	0.1911%	0.467	0.116
48	19.75%	0.1975%	0.483	0.117
49	20.38%	0.2038%	0.498	0.117
50	21.02%	0.2102%	0.514	0.117
51	21.66%	0.2166%	0.529	0.117
52	22.29%	0.2229%	0.545	0.117
53	22.93%	0.2293%	0.561	0.117
54	23.57%	0.2357%	0.576	0.117
55	24.20%	0.2420%	0.592	0.116
56	24.84%	0.2484%	0.607	0.116
57	25.48%	0.2548%	0.623	0.116
58	26.11%	0.2611%	0.639	0.115
59	26.75%	0.2675%	0.654	0.114
60	27.39%	0.2739%	0.670	0.114
61	28.03%	0.2803%	0.685	0.113
62	28.66%	0.2866%	0.701	0.112
63	29.30%	0.2930%	0.716	0.111
64	29.94%	0.2994%	0.732	0.110
65	30.57%	0.3057%	0.748	0.109
66	31.21%	0.3121%	0.763	0.108
67	31.85%	0.3185%	0.779	0.107
68	32.48%	0.3248%	0.794	0.106
69	33.12%	0.3312%	0.810	0.105
70	33.76%	0.3376%	0.825	0.104
71	34.39%	0.3439%	0.841	0.103
72	35.03%	0.3503%	0.857	0.102

73	35.67%	0.3567%	0.872	0.101
74	36.31%	0.3631%	0.888	0.100
75	36.94%	0.3694%	0.903	0.098
76	37.58%	0.3758%	0.919	0.097
77	38.22%	0.3822%	0.934	0.096
78	38.85%	0.3885%	0.950	0.095
79	39.49%	0.3949%	0.966	0.093
80	40.13%	0.4013%	0.981	0.092
81	40.76%	0.4076%	0.997	0.091
82	41.40%	0.4140%	1.012	0.090
83	42.04%	0.4204%	1.028	0.088
84	42.68%	0.4268%	1.043	0.087
85	43.31%	0.4331%	1.059	0.086
86	43.95%	0.4395%	1.075	0.085
87	44.59%	0.4459%	1.090	0.083
88	45.22%	0.4522%	1.106	0.082
89	45.86%	0.4586%	1.121	0.081
90	46.50%	0.4650%	1.137	0.079
91	47.13%	0.4713%	1.152	0.078
92	47.77%	0.4777%	1.168	0.077
93	48.41%	0.4841%	1.184	0.076
94	49.04%	0.4904%	1.199	0.075
95	49.68%	0.4968%	1.215	0.073
96	50.32%	0.5032%	1.230	0.072
97	50.96%	0.5096%	1.246	0.071
98	51.59%	0.5159%	1.261	0.070
99	52.23%	0.5223%	1.277	0.068
100	52.87%	0.5287%	1.293	0.067
101	53.50%	0.5350%	1.308	0.066
102	54.14%	0.5414%	1.324	0.065
103	54.78%	0.5478%	1.339	0.064
104	55.41%	0.5541%	1.355	0.063
105	56.05%	0.5605%	1.370	0.062
106	56.69%	0.5669%	1.386	0.060
107	57.32%	0.5732%	1.402	0.059
108	57.96%	0.5796%	1.417	0.058
109	58.60%	0.5860%	1.433	0.057
110	59.24%	0.5924%	1.448	0.056
111	59.87%	0.5987%	1.464	0.055
112	60.51%	0.6051%	1.479	0.054
113	61.15%	0.6115%	1.495	0.053
114	61.78%	0.6178%	1.511	0.052
115	62.42%	0.6242%	1.526	0.051
116	63.06%	0.6306%	1.542	0.050
117	63.69%	0.6369%	1.557	0.049
118	64.33%	0.6433%	1.573	0.048
119	64.97%	0.6497%	1.588	0.047
120	65.61%	0.6561%	1.604	0.046
121	66.24%	0.6624%	1.620	0.045
122	66.88%	0.6688%	1.635	0.044
123	67.52%	0.6752%	1.651	0.044
124	68.15%	0.6815%	1.666	0.043

125	68.79%	0.6879%	1.682	0.042
126	69.43%	0.6943%	1.697	0.041
127	70.06%	0.7006%	1.713	0.040
128	70.70%	0.7070%	1.729	0.039
129	71.34%	0.7134%	1.744	0.039
130	71.97%	0.7197%	1.760	0.038
131	72.61%	0.7261%	1.775	0.037
132	73.25%	0.7325%	1.791	0.036
133	73.89%	0.7389%	1.806	0.035
134	74.52%	0.7452%	1.822	0.035
135	75.16%	0.7516%	1.838	0.034
136	75.80%	0.7580%	1.853	0.033
137	76.43%	0.7643%	1.869	0.033
138	77.07%	0.7707%	1.884	0.032
139	77.71%	0.7771%	1.900	0.031
140	78.34%	0.7834%	1.916	0.031
141	78.98%	0.7898%	1.931	0.030
142	79.62%	0.7962%	1.947	0.029
143	80.25%	0.8025%	1.962	0.029
144	80.89%	0.8089%	1.978	0.028
145	81.53%	0.8153%	1.993	0.027
146	82.17%	0.8217%	2.009	0.027
147	82.80%	0.8280%	2.025	0.026
148	83.44%	0.8344%	2.040	0.026
149	84.08%	0.8408%	2.056	0.025
150	84.71%	0.8471%	2.071	0.025
151	85.35%	0.8535%	2.087	0.024
152	85.99%	0.8599%	2.102	0.024
153	86.62%	0.8662%	2.118	0.023
154	87.26%	0.8726%	2.134	0.022
155	87.90%	0.8790%	2.149	0.022
156	88.54%	0.8854%	2.165	0.022
157	89.17%	0.8917%	2.180	0.021
158	89.81%	0.8981%	2.196	0.021
159	90.45%	0.9045%	2.211	0.020
160	91.08%	0.9108%	2.227	0.020
161	91.72%	0.9172%	2.243	0.019
162	92.36%	0.9236%	2.258	0.019
163	92.99%	0.9299%	2.274	0.018
164	93.63%	0.9363%	2.289	0.018
165	94.27%	0.9427%	2.305	0.018
166	94.90%	0.9490%	2.320	0.017
167	95.54%	0.9554%	2.336	0.017
168	96.18%	0.9618%	2.352	0.016
169	96.82%	0.9682%	2.367	0.016
170	97.45%	0.9745%	2.383	0.016
171	98.09%	0.9809%	2.398	0.015
172	98.73%	0.9873%	2.414	0.015
173	99.36%	0.9936%	2.429	0.015
174	100.00%	1.0000%	2.445	0.014
Beyond (f)				0.476
Total				10.679

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.000	0.000
1	0.64%	0.0064%	0.016	0.015
2	1.27%	0.0127%	0.031	0.029
3	1.91%	0.0191%	0.047	0.043
4	2.55%	0.0255%	0.062	0.055
5	3.18%	0.0318%	0.078	0.067
6	3.82%	0.0382%	0.093	0.078
7	4.46%	0.0446%	0.109	0.089
8	5.10%	0.0510%	0.125	0.098
9	5.73%	0.0573%	0.140	0.107
10	6.37%	0.0637%	0.156	0.116
11	7.01%	0.0701%	0.171	0.124
12	7.64%	0.0764%	0.187	0.131
13	8.28%	0.0828%	0.202	0.138
14	8.92%	0.0892%	0.218	0.144
15	9.55%	0.0955%	0.234	0.150
16	10.19%	0.1019%	0.249	0.155
17	10.83%	0.1083%	0.265	0.160
18	11.46%	0.1146%	0.280	0.165
19	12.10%	0.1210%	0.296	0.169
20	12.74%	0.1274%	0.311	0.172
21	13.38%	0.1338%	0.327	0.176
22	14.01%	0.1401%	0.343	0.179
23	14.65%	0.1465%	0.358	0.181
24	15.29%	0.1529%	0.374	0.184
25	15.92%	0.1592%	0.389	0.186
26	16.56%	0.1656%	0.405	0.188
27	17.20%	0.1720%	0.420	0.189
28	17.83%	0.1783%	0.436	0.191
29	18.47%	0.1847%	0.452	0.192
30	19.11%	0.1911%	0.467	0.192
31	19.75%	0.1975%	0.483	0.193
32	20.38%	0.2038%	0.498	0.194
33	21.02%	0.2102%	0.514	0.194
34	21.66%	0.2166%	0.529	0.194
35	22.29%	0.2229%	0.545	0.194
36	22.93%	0.2293%	0.561	0.193
37	23.57%	0.2357%	0.576	0.193
38	24.20%	0.2420%	0.592	0.192
39	24.84%	0.2484%	0.607	0.192
40	25.48%	0.2548%	0.623	0.191
41	26.11%	0.2611%	0.639	0.190
42	26.75%	0.2675%	0.654	0.189

43	27.39%	0.2739%	0.670	0.188
44	28.03%	0.2803%	0.685	0.187
45	28.66%	0.2866%	0.701	0.185
46	29.30%	0.2930%	0.716	0.184
47	29.94%	0.2994%	0.732	0.182
48	30.57%	0.3057%	0.748	0.181
49	31.21%	0.3121%	0.763	0.179
50	31.85%	0.3185%	0.779	0.178
51	32.48%	0.3248%	0.794	0.176
52	33.12%	0.3312%	0.810	0.174
53	33.76%	0.3376%	0.825	0.172
54	34.39%	0.3439%	0.841	0.170
55	35.03%	0.3503%	0.857	0.169
56	35.67%	0.3567%	0.872	0.167
57	36.31%	0.3631%	0.888	0.165
58	36.94%	0.3694%	0.903	0.163
59	37.58%	0.3758%	0.919	0.161
60	38.22%	0.3822%	0.934	0.159
61	38.85%	0.3885%	0.950	0.157
62	39.49%	0.3949%	0.966	0.154
63	40.13%	0.4013%	0.981	0.152
64	40.76%	0.4076%	0.997	0.150
65	41.40%	0.4140%	1.012	0.148
66	42.04%	0.4204%	1.028	0.146
67	42.68%	0.4268%	1.043	0.144
68	43.31%	0.4331%	1.059	0.142
69	43.95%	0.4395%	1.075	0.140
70	44.59%	0.4459%	1.090	0.138
71	45.22%	0.4522%	1.106	0.136
72	45.86%	0.4586%	1.121	0.133
73	46.50%	0.4650%	1.137	0.131
74	47.13%	0.4713%	1.152	0.129
75	47.77%	0.4777%	1.168	0.127
76	48.41%	0.4841%	1.184	0.125
77	49.04%	0.4904%	1.199	0.123
78	49.68%	0.4968%	1.215	0.121
79	50.32%	0.5032%	1.230	0.119
80	50.96%	0.5096%	1.246	0.117
81	51.59%	0.5159%	1.261	0.115
82	52.23%	0.5223%	1.277	0.113
83	52.87%	0.5287%	1.293	0.111
84	53.50%	0.5350%	1.308	0.109
85	54.14%	0.5414%	1.324	0.107
86	54.78%	0.5478%	1.339	0.105
87	55.41%	0.5541%	1.355	0.104
88	56.05%	0.5605%	1.370	0.102
89	56.69%	0.5669%	1.386	0.100
90	57.32%	0.5732%	1.402	0.098
91	57.96%	0.5796%	1.417	0.096
92	58.60%	0.5860%	1.433	0.094
93	59.24%	0.5924%	1.448	0.093
94	59.87%	0.5987%	1.464	0.091

95	60.51%	0.6051%	1.479	0.089
96	61.15%	0.6115%	1.495	0.088
97	61.78%	0.6178%	1.511	0.086
98	62.42%	0.6242%	1.526	0.084
99	63.06%	0.6306%	1.542	0.083
100	63.69%	0.6369%	1.557	0.081
101	64.33%	0.6433%	1.573	0.079
102	64.97%	0.6497%	1.588	0.078
103	65.61%	0.6561%	1.604	0.076
104	66.24%	0.6624%	1.620	0.075
105	66.88%	0.6688%	1.635	0.073
106	67.52%	0.6752%	1.651	0.072
107	68.15%	0.6815%	1.666	0.070
108	68.79%	0.6879%	1.682	0.069
109	69.43%	0.6943%	1.697	0.068
110	70.06%	0.7006%	1.713	0.066
111	70.70%	0.7070%	1.729	0.065
112	71.34%	0.7134%	1.744	0.064
113	71.97%	0.7197%	1.760	0.062
114	72.61%	0.7261%	1.775	0.061
115	73.25%	0.7325%	1.791	0.060
116	73.89%	0.7389%	1.806	0.059
117	74.52%	0.7452%	1.822	0.057
118	75.16%	0.7516%	1.838	0.056
119	75.80%	0.7580%	1.853	0.055
120	76.43%	0.7643%	1.869	0.054
121	77.07%	0.7707%	1.884	0.053
122	77.71%	0.7771%	1.900	0.052
123	78.34%	0.7834%	1.916	0.051
124	78.98%	0.7898%	1.931	0.049
125	79.62%	0.7962%	1.947	0.048
126	80.25%	0.8025%	1.962	0.047
127	80.89%	0.8089%	1.978	0.046
128	81.53%	0.8153%	1.993	0.045
129	82.17%	0.8217%	2.009	0.044
130	82.80%	0.8280%	2.025	0.043
131	83.44%	0.8344%	2.040	0.042
132	84.08%	0.8408%	2.056	0.042
133	84.71%	0.8471%	2.071	0.041
134	85.35%	0.8535%	2.087	0.040
135	85.99%	0.8599%	2.102	0.039
136	86.62%	0.8662%	2.118	0.038
137	87.26%	0.8726%	2.134	0.037
138	87.90%	0.8790%	2.149	0.036
139	88.54%	0.8854%	2.165	0.036
140	89.17%	0.8917%	2.180	0.035
141	89.81%	0.8981%	2.196	0.034
142	90.45%	0.9045%	2.211	0.033
143	91.08%	0.9108%	2.227	0.033
144	91.72%	0.9172%	2.243	0.032
145	92.36%	0.9236%	2.258	0.031
146	92.99%	0.9299%	2.274	0.030

147	93.63%	0.9363%	2.289	0.030
148	94.27%	0.9427%	2.305	0.029
149	94.90%	0.9490%	2.320	0.028
150	95.54%	0.9554%	2.336	0.028
151	96.18%	0.9618%	2.352	0.027
152	96.82%	0.9682%	2.367	0.026
153	97.45%	0.9745%	2.383	0.026
154	98.09%	0.9809%	2.398	0.025
155	98.73%	0.9873%	2.414	0.025
156	99.36%	0.9936%	2.429	0.024
157	100.00%	1.0000%	2.445	0.024
Beyond (g)				0.787
Total				17.651

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	63.2
Lake Ashtabula - Jump Dispersal (acres):	71.6

Lower Sheyenne River - Progressive Dispersal (river-miles):	0.803
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.485
Upper Sheyenne River - Jump Dispersal (river-miles):	0.801

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 175 into perpetuity

(f) From year 175 into perpetuity

(g) From year 158 into perpetuity

(h) From year 26 into perpetuity

Appendix 3F. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Slow Invasion - Very High Risk (One Organism)

Probability of successful invasion:	1.00E+00
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0.0	0.0
1	5.88%	5.88%	307.9	298.9
2	11.76%	11.76%	615.8	580.4
3	17.65%	17.65%	923.6	845.3
4	23.53%	23.53%	1,231.5	1,094.2
5	29.41%	29.41%	1,539.4	1,327.9
6	35.29%	35.29%	1,847.3	1,547.1
7	41.18%	41.18%	2,155.2	1,752.4
8	47.06%	47.06%	2,463.1	1,944.4
9	52.94%	52.94%	2,770.9	2,123.7
10	58.82%	58.82%	3,078.8	2,290.9
11	64.71%	64.71%	3,386.7	2,446.6
12	70.59%	70.59%	3,694.6	2,591.3
13	76.47%	76.47%	4,002.5	2,725.5
14	82.35%	82.35%	4,310.4	2,849.7
15	88.24%	88.24%	4,618.2	2,964.3
16	94.12%	94.12%	4,926.1	3,069.8
17	100.00%	100.00%	5,234.0	3,166.7
Beyond (c)				105,555.2
Total				139,174.1

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0.0	0.0
1	12.50%	12.50%	654.3	635.2

2	25.00%	25.00%	1,308.5	1,233.4
3	37.50%	37.50%	1,962.8	1,796.2
4	50.00%	50.00%	2,617.0	2,325.2
5	62.50%	62.50%	3,271.3	2,821.8
6	75.00%	75.00%	3,925.5	3,287.5
7	87.50%	87.50%	4,579.8	3,723.8
8	100.00%	100.00%	5,234.0	4,131.8
Beyond (d)				137,725.6
Total				157,680.4

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0.0	0.0
1	0.57%	0.57%	1.6	1.5
2	1.15%	1.15%	3.1	2.9
3	1.72%	1.72%	4.7	4.3
4	2.30%	2.30%	6.2	5.5
5	2.87%	2.87%	7.8	6.7
6	3.45%	3.45%	9.3	7.8
7	4.02%	4.02%	10.9	8.8
8	4.60%	4.60%	12.4	9.8
9	5.17%	5.17%	14.0	10.7
10	5.75%	5.75%	15.5	11.6
11	6.32%	6.32%	17.1	12.4
12	6.90%	6.90%	18.7	13.1
13	7.47%	7.47%	20.2	13.8
14	8.05%	8.05%	21.8	14.4
15	8.62%	8.62%	23.3	15.0
16	9.20%	9.20%	24.9	15.5
17	9.77%	9.77%	26.4	16.0
18	10.34%	10.34%	28.0	16.4
19	10.92%	10.92%	29.5	16.8
20	11.49%	11.49%	31.1	17.2
21	12.07%	12.07%	32.6	17.5
22	12.64%	12.64%	34.2	17.8
23	13.22%	13.22%	35.8	18.1
24	13.79%	13.79%	37.3	18.4
25	14.37%	14.37%	38.9	18.6
26	14.94%	14.94%	40.4	18.7
27	15.52%	15.52%	42.0	18.9
28	16.09%	16.09%	43.5	19.0
29	16.67%	16.67%	45.1	19.1
30	17.24%	17.24%	46.6	19.2
31	17.82%	17.82%	48.2	19.3
32	18.39%	18.39%	49.7	19.3
33	18.97%	18.97%	51.3	19.3

34	19.54%	19.54%	52.9	19.3
35	20.11%	20.11%	54.4	19.3
36	20.69%	20.69%	56.0	19.3
37	21.26%	21.26%	57.5	19.3
38	21.84%	21.84%	59.1	19.2
39	22.41%	22.41%	60.6	19.1
40	22.99%	22.99%	62.2	19.1
41	23.56%	23.56%	63.7	19.0
42	24.14%	24.14%	65.3	18.9
43	24.71%	24.71%	66.8	18.8
44	25.29%	25.29%	68.4	18.6
45	25.86%	25.86%	70.0	18.5
46	26.44%	26.44%	71.5	18.4
47	27.01%	27.01%	73.1	18.2
48	27.59%	27.59%	74.6	18.1
49	28.16%	28.16%	76.2	17.9
50	28.74%	28.74%	77.7	17.7
51	29.31%	29.31%	79.3	17.6
52	29.89%	29.89%	80.8	17.4
53	30.46%	30.46%	82.4	17.2
54	31.03%	31.03%	83.9	17.0
55	31.61%	31.61%	85.5	16.8
56	32.18%	32.18%	87.1	16.6
57	32.76%	32.76%	88.6	16.4
58	33.33%	33.33%	90.2	16.2
59	33.91%	33.91%	91.7	16.0
60	34.48%	34.48%	93.3	15.8
61	35.06%	35.06%	94.8	15.6
62	35.63%	35.63%	96.4	15.4
63	36.21%	36.21%	97.9	15.2
64	36.78%	36.78%	99.5	15.0
65	37.36%	37.36%	101.0	14.8
66	37.93%	37.93%	102.6	14.6
67	38.51%	38.51%	104.2	14.4
68	39.08%	39.08%	105.7	14.2
69	39.66%	39.66%	107.3	14.0
70	40.23%	40.23%	108.8	13.7
71	40.80%	40.80%	110.4	13.5
72	41.38%	41.38%	111.9	13.3
73	41.95%	41.95%	113.5	13.1
74	42.53%	42.53%	115.0	12.9
75	43.10%	43.10%	116.6	12.7
76	43.68%	43.68%	118.1	12.5
77	44.25%	44.25%	119.7	12.3
78	44.83%	44.83%	121.3	12.1
79	45.40%	45.40%	122.8	11.9
80	45.98%	45.98%	124.4	11.7
81	46.55%	46.55%	125.9	11.5
82	47.13%	47.13%	127.5	11.3
83	47.70%	47.70%	129.0	11.1
84	48.28%	48.28%	130.6	10.9
85	48.85%	48.85%	132.1	10.7

86	49.43%	49.43%	133.7	10.5
87	50.00%	50.00%	135.3	10.3
88	50.57%	50.57%	136.8	10.1
89	51.15%	51.15%	138.4	10.0
90	51.72%	51.72%	139.9	9.8
91	52.30%	52.30%	141.5	9.6
92	52.87%	52.87%	143.0	9.4
93	53.45%	53.45%	144.6	9.3
94	54.02%	54.02%	146.1	9.1
95	54.60%	54.60%	147.7	8.9
96	55.17%	55.17%	149.2	8.7
97	55.75%	55.75%	150.8	8.6
98	56.32%	56.32%	152.4	8.4
99	56.90%	56.90%	153.9	8.2
100	57.47%	57.47%	155.5	8.1
101	58.05%	58.05%	157.0	7.9
102	58.62%	58.62%	158.6	7.8
103	59.20%	59.20%	160.1	7.6
104	59.77%	59.77%	161.7	7.5
105	60.34%	60.34%	163.2	7.3
106	60.92%	60.92%	164.8	7.2
107	61.49%	61.49%	166.3	7.0
108	62.07%	62.07%	167.9	6.9
109	62.64%	62.64%	169.5	6.8
110	63.22%	63.22%	171.0	6.6
111	63.79%	63.79%	172.6	6.5
112	64.37%	64.37%	174.1	6.4
113	64.94%	64.94%	175.7	6.2
114	65.52%	65.52%	177.2	6.1
115	66.09%	66.09%	178.8	6.0
116	66.67%	66.67%	180.3	5.8
117	67.24%	67.24%	181.9	5.7
118	67.82%	67.82%	183.4	5.6
119	68.39%	68.39%	185.0	5.5
120	68.97%	68.97%	186.6	5.4
121	69.54%	69.54%	188.1	5.3
122	70.11%	70.11%	189.7	5.2
123	70.69%	70.69%	191.2	5.0
124	71.26%	71.26%	192.8	4.9
125	71.84%	71.84%	194.3	4.8
126	72.41%	72.41%	195.9	4.7
127	72.99%	72.99%	197.4	4.6
128	73.56%	73.56%	199.0	4.5
129	74.14%	74.14%	200.5	4.4
130	74.71%	74.71%	202.1	4.3
131	75.29%	75.29%	203.7	4.2
132	75.86%	75.86%	205.2	4.1
133	76.44%	76.44%	206.8	4.1
134	77.01%	77.01%	208.3	4.0
135	77.59%	77.59%	209.9	3.9
136	78.16%	78.16%	211.4	3.8
137	78.74%	78.74%	213.0	3.7

138	79.31%	79.31%	214.5	3.6
139	79.89%	79.89%	216.1	3.6
140	80.46%	80.46%	217.6	3.5
141	81.03%	81.03%	219.2	3.4
142	81.61%	81.61%	220.8	3.3
143	82.18%	82.18%	222.3	3.2
144	82.76%	82.76%	223.9	3.2
145	83.33%	83.33%	225.4	3.1
146	83.91%	83.91%	227.0	3.0
147	84.48%	84.48%	228.5	3.0
148	85.06%	85.06%	230.1	2.9
149	85.63%	85.63%	231.6	2.8
150	86.21%	86.21%	233.2	2.8
151	86.78%	86.78%	234.7	2.7
152	87.36%	87.36%	236.3	2.6
153	87.93%	87.93%	237.9	2.6
154	88.51%	88.51%	239.4	2.5
155	89.08%	89.08%	241.0	2.5
156	89.66%	89.66%	242.5	2.4
157	90.23%	90.23%	244.1	2.4
158	90.80%	90.80%	245.6	2.3
159	91.38%	91.38%	247.2	2.2
160	91.95%	91.95%	248.7	2.2
161	92.53%	92.53%	250.3	2.1
162	93.10%	93.10%	251.8	2.1
163	93.68%	93.68%	253.4	2.0
164	94.25%	94.25%	255.0	2.0
165	94.83%	94.83%	256.5	2.0
166	95.40%	95.40%	258.1	1.9
167	95.98%	95.98%	259.6	1.9
168	96.55%	96.55%	261.2	1.8
169	97.13%	97.13%	262.7	1.8
170	97.70%	97.70%	264.3	1.7
171	98.28%	98.28%	265.8	1.7
172	98.85%	98.85%	267.4	1.7
173	99.43%	99.43%	268.9	1.6
174	100.00%	100.00%	270.5	1.6
Beyond (e)				52.6
Total				1,768.8

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
17	0.00%	0.00%	0.0	0.0
18	0.64%	0.64%	1.6	0.9
19	1.27%	1.27%	3.1	1.8
20	1.91%	1.91%	4.7	2.6

21	2.55%	2.55%	6.2	3.3
22	3.18%	3.18%	7.8	4.1
23	3.82%	3.82%	9.3	4.7
24	4.46%	4.46%	10.9	5.4
25	5.10%	5.10%	12.5	6.0
26	5.73%	5.73%	14.0	6.5
27	6.37%	6.37%	15.6	7.0
28	7.01%	7.01%	17.1	7.5
29	7.64%	7.64%	18.7	7.9
30	8.28%	8.28%	20.2	8.3
31	8.92%	8.92%	21.8	8.7
32	9.55%	9.55%	23.4	9.1
33	10.19%	10.19%	24.9	9.4
34	10.83%	10.83%	26.5	9.7
35	11.46%	11.46%	28.0	10.0
36	12.10%	12.10%	29.6	10.2
37	12.74%	12.74%	31.1	10.4
38	13.38%	13.38%	32.7	10.6
39	14.01%	14.01%	34.3	10.8
40	14.65%	14.65%	35.8	11.0
41	15.29%	15.29%	37.4	11.1
42	15.92%	15.92%	38.9	11.3
43	16.56%	16.56%	40.5	11.4
44	17.20%	17.20%	42.0	11.5
45	17.83%	17.83%	43.6	11.5
46	18.47%	18.47%	45.2	11.6
47	19.11%	19.11%	46.7	11.6
48	19.75%	19.75%	48.3	11.7
49	20.38%	20.38%	49.8	11.7
50	21.02%	21.02%	51.4	11.7
51	21.66%	21.66%	52.9	11.7
52	22.29%	22.29%	54.5	11.7
53	22.93%	22.93%	56.1	11.7
54	23.57%	23.57%	57.6	11.7
55	24.20%	24.20%	59.2	11.6
56	24.84%	24.84%	60.7	11.6
57	25.48%	25.48%	62.3	11.6
58	26.11%	26.11%	63.9	11.5
59	26.75%	26.75%	65.4	11.4
60	27.39%	27.39%	67.0	11.4
61	28.03%	28.03%	68.5	11.3
62	28.66%	28.66%	70.1	11.2
63	29.30%	29.30%	71.6	11.1
64	29.94%	29.94%	73.2	11.0
65	30.57%	30.57%	74.8	10.9
66	31.21%	31.21%	76.3	10.8
67	31.85%	31.85%	77.9	10.7
68	32.48%	32.48%	79.4	10.6
69	33.12%	33.12%	81.0	10.5
70	33.76%	33.76%	82.5	10.4
71	34.39%	34.39%	84.1	10.3
72	35.03%	35.03%	85.7	10.2

73	35.67%	35.67%	87.2	10.1
74	36.31%	36.31%	88.8	10.0
75	36.94%	36.94%	90.3	9.8
76	37.58%	37.58%	91.9	9.7
77	38.22%	38.22%	93.4	9.6
78	38.85%	38.85%	95.0	9.5
79	39.49%	39.49%	96.6	9.3
80	40.13%	40.13%	98.1	9.2
81	40.76%	40.76%	99.7	9.1
82	41.40%	41.40%	101.2	9.0
83	42.04%	42.04%	102.8	8.8
84	42.68%	42.68%	104.3	8.7
85	43.31%	43.31%	105.9	8.6
86	43.95%	43.95%	107.5	8.5
87	44.59%	44.59%	109.0	8.3
88	45.22%	45.22%	110.6	8.2
89	45.86%	45.86%	112.1	8.1
90	46.50%	46.50%	113.7	7.9
91	47.13%	47.13%	115.2	7.8
92	47.77%	47.77%	116.8	7.7
93	48.41%	48.41%	118.4	7.6
94	49.04%	49.04%	119.9	7.5
95	49.68%	49.68%	121.5	7.3
96	50.32%	50.32%	123.0	7.2
97	50.96%	50.96%	124.6	7.1
98	51.59%	51.59%	126.1	7.0
99	52.23%	52.23%	127.7	6.8
100	52.87%	52.87%	129.3	6.7
101	53.50%	53.50%	130.8	6.6
102	54.14%	54.14%	132.4	6.5
103	54.78%	54.78%	133.9	6.4
104	55.41%	55.41%	135.5	6.3
105	56.05%	56.05%	137.0	6.2
106	56.69%	56.69%	138.6	6.0
107	57.32%	57.32%	140.2	5.9
108	57.96%	57.96%	141.7	5.8
109	58.60%	58.60%	143.3	5.7
110	59.24%	59.24%	144.8	5.6
111	59.87%	59.87%	146.4	5.5
112	60.51%	60.51%	147.9	5.4
113	61.15%	61.15%	149.5	5.3
114	61.78%	61.78%	151.1	5.2
115	62.42%	62.42%	152.6	5.1
116	63.06%	63.06%	154.2	5.0
117	63.69%	63.69%	155.7	4.9
118	64.33%	64.33%	157.3	4.8
119	64.97%	64.97%	158.8	4.7
120	65.61%	65.61%	160.4	4.6
121	66.24%	66.24%	162.0	4.5
122	66.88%	66.88%	163.5	4.4
123	67.52%	67.52%	165.1	4.4
124	68.15%	68.15%	166.6	4.3

125	68.79%	68.79%	168.2	4.2
126	69.43%	69.43%	169.7	4.1
127	70.06%	70.06%	171.3	4.0
128	70.70%	70.70%	172.9	3.9
129	71.34%	71.34%	174.4	3.9
130	71.97%	71.97%	176.0	3.8
131	72.61%	72.61%	177.5	3.7
132	73.25%	73.25%	179.1	3.6
133	73.89%	73.89%	180.6	3.5
134	74.52%	74.52%	182.2	3.5
135	75.16%	75.16%	183.8	3.4
136	75.80%	75.80%	185.3	3.3
137	76.43%	76.43%	186.9	3.3
138	77.07%	77.07%	188.4	3.2
139	77.71%	77.71%	190.0	3.1
140	78.34%	78.34%	191.6	3.1
141	78.98%	78.98%	193.1	3.0
142	79.62%	79.62%	194.7	2.9
143	80.25%	80.25%	196.2	2.9
144	80.89%	80.89%	197.8	2.8
145	81.53%	81.53%	199.3	2.7
146	82.17%	82.17%	200.9	2.7
147	82.80%	82.80%	202.5	2.6
148	83.44%	83.44%	204.0	2.6
149	84.08%	84.08%	205.6	2.5
150	84.71%	84.71%	207.1	2.5
151	85.35%	85.35%	208.7	2.4
152	85.99%	85.99%	210.2	2.4
153	86.62%	86.62%	211.8	2.3
154	87.26%	87.26%	213.4	2.2
155	87.90%	87.90%	214.9	2.2
156	88.54%	88.54%	216.5	2.2
157	89.17%	89.17%	218.0	2.1
158	89.81%	89.81%	219.6	2.1
159	90.45%	90.45%	221.1	2.0
160	91.08%	91.08%	222.7	2.0
161	91.72%	91.72%	224.3	1.9
162	92.36%	92.36%	225.8	1.9
163	92.99%	92.99%	227.4	1.8
164	93.63%	93.63%	228.9	1.8
165	94.27%	94.27%	230.5	1.8
166	94.90%	94.90%	232.0	1.7
167	95.54%	95.54%	233.6	1.7
168	96.18%	96.18%	235.2	1.6
169	96.82%	96.82%	236.7	1.6
170	97.45%	97.45%	238.3	1.6
171	98.09%	98.09%	239.8	1.5
172	98.73%	98.73%	241.4	1.5
173	99.36%	99.36%	242.9	1.5
174	100.00%	100.00%	244.5	1.4
Beyond (f)				47.6
Total				1,067.9

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0.0	0.0
1	0.64%	0.64%	1.6	1.5
2	1.27%	1.27%	3.1	2.9
3	1.91%	1.91%	4.7	4.3
4	2.55%	2.55%	6.2	5.5
5	3.18%	3.18%	7.8	6.7
6	3.82%	3.82%	9.3	7.8
7	4.46%	4.46%	10.9	8.9
8	5.10%	5.10%	12.5	9.8
9	5.73%	5.73%	14.0	10.7
10	6.37%	6.37%	15.6	11.6
11	7.01%	7.01%	17.1	12.4
12	7.64%	7.64%	18.7	13.1
13	8.28%	8.28%	20.2	13.8
14	8.92%	8.92%	21.8	14.4
15	9.55%	9.55%	23.4	15.0
16	10.19%	10.19%	24.9	15.5
17	10.83%	10.83%	26.5	16.0
18	11.46%	11.46%	28.0	16.5
19	12.10%	12.10%	29.6	16.9
20	12.74%	12.74%	31.1	17.2
21	13.38%	13.38%	32.7	17.6
22	14.01%	14.01%	34.3	17.9
23	14.65%	14.65%	35.8	18.1
24	15.29%	15.29%	37.4	18.4
25	15.92%	15.92%	38.9	18.6
26	16.56%	16.56%	40.5	18.8
27	17.20%	17.20%	42.0	18.9
28	17.83%	17.83%	43.6	19.1
29	18.47%	18.47%	45.2	19.2
30	19.11%	19.11%	46.7	19.2
31	19.75%	19.75%	48.3	19.3
32	20.38%	20.38%	49.8	19.4
33	21.02%	21.02%	51.4	19.4
34	21.66%	21.66%	52.9	19.4
35	22.29%	22.29%	54.5	19.4
36	22.93%	22.93%	56.1	19.3
37	23.57%	23.57%	57.6	19.3
38	24.20%	24.20%	59.2	19.2
39	24.84%	24.84%	60.7	19.2
40	25.48%	25.48%	62.3	19.1
41	26.11%	26.11%	63.9	19.0
42	26.75%	26.75%	65.4	18.9

43	27.39%	27.39%	67.0	18.8
44	28.03%	28.03%	68.5	18.7
45	28.66%	28.66%	70.1	18.5
46	29.30%	29.30%	71.6	18.4
47	29.94%	29.94%	73.2	18.2
48	30.57%	30.57%	74.8	18.1
49	31.21%	31.21%	76.3	17.9
50	31.85%	31.85%	77.9	17.8
51	32.48%	32.48%	79.4	17.6
52	33.12%	33.12%	81.0	17.4
53	33.76%	33.76%	82.5	17.2
54	34.39%	34.39%	84.1	17.0
55	35.03%	35.03%	85.7	16.9
56	35.67%	35.67%	87.2	16.7
57	36.31%	36.31%	88.8	16.5
58	36.94%	36.94%	90.3	16.3
59	37.58%	37.58%	91.9	16.1
60	38.22%	38.22%	93.4	15.9
61	38.85%	38.85%	95.0	15.7
62	39.49%	39.49%	96.6	15.4
63	40.13%	40.13%	98.1	15.2
64	40.76%	40.76%	99.7	15.0
65	41.40%	41.40%	101.2	14.8
66	42.04%	42.04%	102.8	14.6
67	42.68%	42.68%	104.3	14.4
68	43.31%	43.31%	105.9	14.2
69	43.95%	43.95%	107.5	14.0
70	44.59%	44.59%	109.0	13.8
71	45.22%	45.22%	110.6	13.6
72	45.86%	45.86%	112.1	13.3
73	46.50%	46.50%	113.7	13.1
74	47.13%	47.13%	115.2	12.9
75	47.77%	47.77%	116.8	12.7
76	48.41%	48.41%	118.4	12.5
77	49.04%	49.04%	119.9	12.3
78	49.68%	49.68%	121.5	12.1
79	50.32%	50.32%	123.0	11.9
80	50.96%	50.96%	124.6	11.7
81	51.59%	51.59%	126.1	11.5
82	52.23%	52.23%	127.7	11.3
83	52.87%	52.87%	129.3	11.1
84	53.50%	53.50%	130.8	10.9
85	54.14%	54.14%	132.4	10.7
86	54.78%	54.78%	133.9	10.5
87	55.41%	55.41%	135.5	10.4
88	56.05%	56.05%	137.0	10.2
89	56.69%	56.69%	138.6	10.0
90	57.32%	57.32%	140.2	9.8
91	57.96%	57.96%	141.7	9.6
92	58.60%	58.60%	143.3	9.4
93	59.24%	59.24%	144.8	9.3
94	59.87%	59.87%	146.4	9.1

95	60.51%	60.51%	147.9	8.9
96	61.15%	61.15%	149.5	8.8
97	61.78%	61.78%	151.1	8.6
98	62.42%	62.42%	152.6	8.4
99	63.06%	63.06%	154.2	8.3
100	63.69%	63.69%	155.7	8.1
101	64.33%	64.33%	157.3	7.9
102	64.97%	64.97%	158.8	7.8
103	65.61%	65.61%	160.4	7.6
104	66.24%	66.24%	162.0	7.5
105	66.88%	66.88%	163.5	7.3
106	67.52%	67.52%	165.1	7.2
107	68.15%	68.15%	166.6	7.0
108	68.79%	68.79%	168.2	6.9
109	69.43%	69.43%	169.7	6.8
110	70.06%	70.06%	171.3	6.6
111	70.70%	70.70%	172.9	6.5
112	71.34%	71.34%	174.4	6.4
113	71.97%	71.97%	176.0	6.2
114	72.61%	72.61%	177.5	6.1
115	73.25%	73.25%	179.1	6.0
116	73.89%	73.89%	180.6	5.9
117	74.52%	74.52%	182.2	5.7
118	75.16%	75.16%	183.8	5.6
119	75.80%	75.80%	185.3	5.5
120	76.43%	76.43%	186.9	5.4
121	77.07%	77.07%	188.4	5.3
122	77.71%	77.71%	190.0	5.2
123	78.34%	78.34%	191.6	5.1
124	78.98%	78.98%	193.1	4.9
125	79.62%	79.62%	194.7	4.8
126	80.25%	80.25%	196.2	4.7
127	80.89%	80.89%	197.8	4.6
128	81.53%	81.53%	199.3	4.5
129	82.17%	82.17%	200.9	4.4
130	82.80%	82.80%	202.5	4.3
131	83.44%	83.44%	204.0	4.2
132	84.08%	84.08%	205.6	4.2
133	84.71%	84.71%	207.1	4.1
134	85.35%	85.35%	208.7	4.0
135	85.99%	85.99%	210.2	3.9
136	86.62%	86.62%	211.8	3.8
137	87.26%	87.26%	213.4	3.7
138	87.90%	87.90%	214.9	3.6
139	88.54%	88.54%	216.5	3.6
140	89.17%	89.17%	218.0	3.5
141	89.81%	89.81%	219.6	3.4
142	90.45%	90.45%	221.1	3.3
143	91.08%	91.08%	222.7	3.3
144	91.72%	91.72%	224.3	3.2
145	92.36%	92.36%	225.8	3.1
146	92.99%	92.99%	227.4	3.0

147	93.63%	93.63%	228.9	3.0
148	94.27%	94.27%	230.5	2.9
149	94.90%	94.90%	232.0	2.8
150	95.54%	95.54%	233.6	2.8
151	96.18%	96.18%	235.2	2.7
152	96.82%	96.82%	236.7	2.6
153	97.45%	97.45%	238.3	2.6
154	98.09%	98.09%	239.8	2.5
155	98.73%	98.73%	241.4	2.5
156	99.36%	99.36%	242.9	2.4
157	100.00%	100.00%	244.5	2.4
Beyond (g)				78.7
Total				1,765.1

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres): 6,320

Lake Ashtabula - Jump Dispersal (acres): 7,160

Lower Sheyenne River - Progressive Dispersal (river-miles):	80.3
Upper Sheyenne River - Progressive Dispersal (river-miles):	48.5
Upper Sheyenne River - Jump Dispersal (river-miles):	80.1

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 18 into perpetuity

(d) From year 9 into perpetuity

(e) From year 175 into perpetuity

(f) From year 175 into perpetuity

(g) From year 158 into perpetuity

(h) From year 26 into perpetuity

Appendix 3G. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Fast Invasion - Very Low Risk (One Organism)

Probability of successful invasion:	1.00E-09
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.000000000	0.000000000
1	100.00%	0.00000010000%	0.000005234	0.000005082
Beyond (c)				0.000169385
Total				0.000174467

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	0.00000010000%	0.000005234	0.000005234
Beyond (d)				0.000174467
Total				0.000179701

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.000000000	0.000000000
1	5.88%	0.00000000588%	0.000000016	0.000000015
2	11.76%	0.00000001176%	0.000000032	0.000000030
3	17.65%	0.00000001765%	0.000000048	0.000000044
4	23.53%	0.00000002353%	0.000000064	0.000000057
5	29.41%	0.00000002941%	0.000000080	0.000000069

6	35.29%	0.00000003529%	0.000000095	0.000000080
7	41.18%	0.00000004118%	0.000000111	0.000000091
8	47.06%	0.00000004706%	0.000000127	0.000000100
9	52.94%	0.00000005294%	0.000000143	0.000000110
10	58.82%	0.00000005882%	0.000000159	0.000000118
11	64.71%	0.00000006471%	0.000000175	0.000000126
12	70.59%	0.00000007059%	0.000000191	0.000000134
13	76.47%	0.00000007647%	0.000000207	0.000000141
14	82.35%	0.00000008235%	0.000000223	0.000000147
15	88.24%	0.00000008824%	0.000000239	0.000000153
16	94.12%	0.00000009412%	0.000000255	0.000000159
17	100.00%	0.00000010000%	0.000000271	0.000000164
Beyond (e)				0.000005455
Total				0.000007193

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.00000000000%	0.000000000	0.000000000
2	6.67%	0.00000000667%	0.000000016	0.000000015
3	13.33%	0.00000001333%	0.000000033	0.000000030
4	20.00%	0.00000002000%	0.000000049	0.000000043
5	26.67%	0.00000002667%	0.000000065	0.000000056
6	33.33%	0.00000003333%	0.000000082	0.000000068
7	40.00%	0.00000004000%	0.000000098	0.000000080
8	46.67%	0.00000004667%	0.000000114	0.000000090
9	53.33%	0.00000005333%	0.000000130	0.000000100
10	60.00%	0.00000006000%	0.000000147	0.000000109
11	66.67%	0.00000006667%	0.000000163	0.000000118
12	73.33%	0.00000007333%	0.000000179	0.000000126
13	80.00%	0.00000008000%	0.000000196	0.000000133
14	86.67%	0.00000008667%	0.000000212	0.000000140
15	93.33%	0.00000009333%	0.000000228	0.000000146
16	100.00%	0.00000010000%	0.000000245	0.000000152
Beyond (f)				0.000005079
Total				0.000006486

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000000%	0.000000000	0.000000000
1	6.67%	0.00000000667%	0.000000016	0.000000016

2	13.33%	0.00000001333%	0.000000033	0.000000031
3	20.00%	0.00000002000%	0.000000049	0.000000045
4	26.67%	0.00000002667%	0.000000065	0.000000058
5	33.33%	0.00000003333%	0.000000082	0.000000070
6	40.00%	0.00000004000%	0.000000098	0.000000082
7	46.67%	0.00000004667%	0.000000114	0.000000093
8	53.33%	0.00000005333%	0.000000130	0.000000103
9	60.00%	0.00000006000%	0.000000147	0.000000112
10	66.67%	0.00000006667%	0.000000163	0.000000121
11	73.33%	0.00000007333%	0.000000179	0.000000130
12	80.00%	0.00000008000%	0.000000196	0.000000137
13	86.67%	0.00000008667%	0.000000212	0.000000144
14	93.33%	0.00000009333%	0.000000228	0.000000151
15	100.00%	0.00000010000%	0.000000245	0.000000157
Beyond (g)				0.000005231
Total				0.000006681

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	0.00000792
Lake Ashtabula - Jump Dispersal (acres):	0.00000816
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.000000326
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.000000294
Upper Sheyenne River - Jump Dispersal (river-miles):	0.000000303

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 18 into perpetuity

(f) From year 17 into perpetuity

(g) From year 16 into perpetuity

(h) From year 26 into perpetuity

Appendix 3H. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Fast Invasion - Low Risk (One Organism)

Probability of successful invasion:	1.00E-06
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.000000	0.000000
1	100.00%	0.00010000%	0.005234	0.005082
Beyond (c)				0.169385
Total				0.174467

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	0.00010000%	0.005234	0.005234
Beyond (d)				0.174467
Total				0.179701

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.000000	0.000000
1	5.88%	0.00000588%	0.000016	0.000015
2	11.76%	0.00001176%	0.000032	0.000030
3	17.65%	0.00001765%	0.000048	0.000044
4	23.53%	0.00002353%	0.000064	0.000057
5	29.41%	0.00002941%	0.000080	0.000069

6	35.29%	0.00003529%	0.000095	0.000080
7	41.18%	0.00004118%	0.000111	0.000091
8	47.06%	0.00004706%	0.000127	0.000100
9	52.94%	0.00005294%	0.000143	0.000110
10	58.82%	0.00005882%	0.000159	0.000118
11	64.71%	0.00006471%	0.000175	0.000126
12	70.59%	0.00007059%	0.000191	0.000134
13	76.47%	0.00007647%	0.000207	0.000141
14	82.35%	0.00008235%	0.000223	0.000147
15	88.24%	0.00008824%	0.000239	0.000153
16	94.12%	0.00009412%	0.000255	0.000159
17	100.00%	0.00010000%	0.000271	0.000164
Beyond (e)				0.005455
Total				0.007193

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.00000000%	0.000000	0.000000
2	6.67%	0.00000667%	0.000016	0.000015
3	13.33%	0.00001333%	0.000033	0.000030
4	20.00%	0.00002000%	0.000049	0.000043
5	26.67%	0.00002667%	0.000065	0.000056
6	33.33%	0.00003333%	0.000082	0.000068
7	40.00%	0.00004000%	0.000098	0.000080
8	46.67%	0.00004667%	0.000114	0.000090
9	53.33%	0.00005333%	0.000130	0.000100
10	60.00%	0.00006000%	0.000147	0.000109
11	66.67%	0.00006667%	0.000163	0.000118
12	73.33%	0.00007333%	0.000179	0.000126
13	80.00%	0.00008000%	0.000196	0.000133
14	86.67%	0.00008667%	0.000212	0.000140
15	93.33%	0.00009333%	0.000228	0.000146
16	100.00%	0.00010000%	0.000245	0.000152
Beyond (f)				0.005079
Total				0.006486

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000000%	0.000000	0.000000
1	6.67%	0.00000667%	0.000016	0.000016

2	13.33%	0.00001333%	0.000033	0.000031
3	20.00%	0.00002000%	0.000049	0.000045
4	26.67%	0.00002667%	0.000065	0.000058
5	33.33%	0.00003333%	0.000082	0.000070
6	40.00%	0.00004000%	0.000098	0.000082
7	46.67%	0.00004667%	0.000114	0.000093
8	53.33%	0.00005333%	0.000130	0.000103
9	60.00%	0.00006000%	0.000147	0.000112
10	66.67%	0.00006667%	0.000163	0.000121
11	73.33%	0.00007333%	0.000179	0.000130
12	80.00%	0.00008000%	0.000196	0.000137
13	86.67%	0.00008667%	0.000212	0.000144
14	93.33%	0.00009333%	0.000228	0.000151
15	100.00%	0.00010000%	0.000245	0.000157
Beyond (g)				0.005231
Total				0.006681

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	0.00792
Lake Ashtabula - Jump Dispersal (acres):	0.00816
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.000326
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.000294
Upper Sheyenne River - Jump Dispersal (river-miles):	0.000303

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 18 into perpetuity

(f) From year 17 into perpetuity

(g) From year 16 into perpetuity

(h) From year 26 into perpetuity

Appendix 3I. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Fast Invasion - Moderate Risk (One Organism)

Probability of successful invasion: 1.00E-03

Annual discount rate: 3.0%

Present year: 0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.000	0.000
1	100.00%	0.10000%	5.234	5.082
Beyond (c)				169.385
Total				174.467

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	0.10000%	5.234	5.234
Beyond (d)				174.467
Total				179.701

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.000	0.000
1	5.88%	0.00588%	0.016	0.015
2	11.76%	0.01176%	0.032	0.030
3	17.65%	0.01765%	0.048	0.044
4	23.53%	0.02353%	0.064	0.057
5	29.41%	0.02941%	0.080	0.069

6	35.29%	0.03529%	0.095	0.080
7	41.18%	0.04118%	0.111	0.091
8	47.06%	0.04706%	0.127	0.100
9	52.94%	0.05294%	0.143	0.110
10	58.82%	0.05882%	0.159	0.118
11	64.71%	0.06471%	0.175	0.126
12	70.59%	0.07059%	0.191	0.134
13	76.47%	0.07647%	0.207	0.141
14	82.35%	0.08235%	0.223	0.147
15	88.24%	0.08824%	0.239	0.153
16	94.12%	0.09412%	0.255	0.159
17	100.00%	0.10000%	0.271	0.164
Beyond (e)				5.455
Total				7.193

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.00000%	0.000	0.000
2	6.67%	0.00667%	0.016	0.015
3	13.33%	0.01333%	0.033	0.030
4	20.00%	0.02000%	0.049	0.043
5	26.67%	0.02667%	0.065	0.056
6	33.33%	0.03333%	0.082	0.068
7	40.00%	0.04000%	0.098	0.080
8	46.67%	0.04667%	0.114	0.090
9	53.33%	0.05333%	0.130	0.100
10	60.00%	0.06000%	0.147	0.109
11	66.67%	0.06667%	0.163	0.118
12	73.33%	0.07333%	0.179	0.126
13	80.00%	0.08000%	0.196	0.133
14	86.67%	0.08667%	0.212	0.140
15	93.33%	0.09333%	0.228	0.146
16	100.00%	0.10000%	0.245	0.152
Beyond (f)				5.079
Total				6.486

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00000%	0.000	0.000
1	6.67%	0.00667%	0.016	0.016

2	13.33%	0.01333%	0.033	0.031
3	20.00%	0.02000%	0.049	0.045
4	26.67%	0.02667%	0.065	0.058
5	33.33%	0.03333%	0.082	0.070
6	40.00%	0.04000%	0.098	0.082
7	46.67%	0.04667%	0.114	0.093
8	53.33%	0.05333%	0.130	0.103
9	60.00%	0.06000%	0.147	0.112
10	66.67%	0.06667%	0.163	0.121
11	73.33%	0.07333%	0.179	0.130
12	80.00%	0.08000%	0.196	0.137
13	86.67%	0.08667%	0.212	0.144
14	93.33%	0.09333%	0.228	0.151
15	100.00%	0.10000%	0.245	0.157
Beyond (g)				5.231
Total				6.681

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	7.92
Lake Ashtabula - Jump Dispersal (acres):	8.16
Lower Sheyenne River - Progressive Dispersal (river-miles):	0.326
Upper Sheyenne River - Progressive Dispersal (river-miles):	0.294
Upper Sheyenne River - Jump Dispersal (river-miles):	0.303

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 18 into perpetuity

(f) From year 17 into perpetuity

(g) From year 16 into perpetuity

(h) From year 26 into perpetuity

Appendix 3J. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Fast Invasion - High Risk (One Organism)

Probability of successful invasion:	1.00E-02
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.00	0.00
1	100.00%	1.0000%	52.34	50.82
Beyond (c)				1,693.85
Total				1,744.67

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	1.0000%	52.34	52.34
Beyond (d)				1,744.67
Total				1,797.01

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.00	0.00
1	5.88%	0.0588%	0.16	0.15
2	11.76%	0.1176%	0.32	0.30
3	17.65%	0.1765%	0.48	0.44
4	23.53%	0.2353%	0.64	0.57
5	29.41%	0.2941%	0.80	0.69

6	35.29%	0.3529%	0.95	0.80
7	41.18%	0.4118%	1.11	0.91
8	47.06%	0.4706%	1.27	1.00
9	52.94%	0.5294%	1.43	1.10
10	58.82%	0.5882%	1.59	1.18
11	64.71%	0.6471%	1.75	1.26
12	70.59%	0.7059%	1.91	1.34
13	76.47%	0.7647%	2.07	1.41
14	82.35%	0.8235%	2.23	1.47
15	88.24%	0.8824%	2.39	1.53
16	94.12%	0.9412%	2.55	1.59
17	100.00%	1.0000%	2.71	1.64
Beyond (e)				54.55
Total				71.93

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.0000%	0.00	0.00
2	6.67%	0.0667%	0.16	0.15
3	13.33%	0.1333%	0.33	0.30
4	20.00%	0.2000%	0.49	0.43
5	26.67%	0.2667%	0.65	0.56
6	33.33%	0.3333%	0.82	0.68
7	40.00%	0.4000%	0.98	0.80
8	46.67%	0.4667%	1.14	0.90
9	53.33%	0.5333%	1.30	1.00
10	60.00%	0.6000%	1.47	1.09
11	66.67%	0.6667%	1.63	1.18
12	73.33%	0.7333%	1.79	1.26
13	80.00%	0.8000%	1.96	1.33
14	86.67%	0.8667%	2.12	1.40
15	93.33%	0.9333%	2.28	1.46
16	100.00%	1.0000%	2.45	1.52
Beyond (f)				50.79
Total				64.86

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.0000%	0.00	0.00
1	6.67%	0.0667%	0.16	0.16

2	13.33%	0.1333%	0.33	0.31
3	20.00%	0.2000%	0.49	0.45
4	26.67%	0.2667%	0.65	0.58
5	33.33%	0.3333%	0.82	0.70
6	40.00%	0.4000%	0.98	0.82
7	46.67%	0.4667%	1.14	0.93
8	53.33%	0.5333%	1.30	1.03
9	60.00%	0.6000%	1.47	1.12
10	66.67%	0.6667%	1.63	1.21
11	73.33%	0.7333%	1.79	1.30
12	80.00%	0.8000%	1.96	1.37
13	86.67%	0.8667%	2.12	1.44
14	93.33%	0.9333%	2.28	1.51
15	100.00%	1.0000%	2.45	1.57
Beyond (g)				52.31
Total				66.81

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	79.2
Lake Ashtabula - Jump Dispersal (acres):	81.6
Lower Sheyenne River - Progressive Dispersal (river-miles):	3.26
Upper Sheyenne River - Progressive Dispersal (river-miles):	2.94
Upper Sheyenne River - Jump Dispersal (river-miles):	3.03

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 18 into perpetuity

(f) From year 17 into perpetuity

(g) From year 16 into perpetuity

(h) From year 26 into perpetuity

Appendix 3K. Habitat Equivalency Analysis of Risk Consequences: Missouri River Import to Red River Valley, Fast Invasion - Very High Risk (One Organism)

Probability of successful invasion:	1.00E+00
Annual discount rate:	3.0%
Present year:	0

Section 1 Quantification of Expected Lost Services

Section 1.1 Lake Ashtabula - Progressive Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0	0
1	100.00%	100.00%	5,234	5,082
Beyond (c)				169,385
Total				174,467

Section 1.2 Lake Ashtabula - Jump Dispersal

Affected habitat (acres): 5,234.00

	<------------(Percentage)------------>		<------------------(Acre Years)------------------>	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	100.00%	100.00%	5,234	5,234
Beyond (d)				174,467
Total				179,701

Section 1.3 Lower Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 270.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0	0
1	5.88%	5.88%	16	15
2	11.76%	11.76%	32	30
3	17.65%	17.65%	48	44
4	23.53%	23.53%	64	57
5	29.41%	29.41%	80	69

6	35.29%	35.29%	95	80
7	41.18%	41.18%	111	91
8	47.06%	47.06%	127	100
9	52.94%	52.94%	143	110
10	58.82%	58.82%	159	118
11	64.71%	64.71%	175	126
12	70.59%	70.59%	191	134
13	76.47%	76.47%	207	141
14	82.35%	82.35%	223	147
15	88.24%	88.24%	239	153
16	94.12%	94.12%	255	159
17	100.00%	100.00%	271	164
Beyond (e)				5,455
Total				7,193

Section 1.4 Upper Sheyenne River - Progressive Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
1	0.00%	0.00%	0	0
2	6.67%	6.67%	16	15
3	13.33%	13.33%	33	30
4	20.00%	20.00%	49	43
5	26.67%	26.67%	65	56
6	33.33%	33.33%	82	68
7	40.00%	40.00%	98	80
8	46.67%	46.67%	114	90
9	53.33%	53.33%	130	100
10	60.00%	60.00%	147	109
11	66.67%	66.67%	163	118
12	73.33%	73.33%	179	126
13	80.00%	80.00%	196	133
14	86.67%	86.67%	212	140
15	93.33%	93.33%	228	146
16	100.00%	100.00%	245	152
Beyond (f)				5,079
Total				6,486

Section 1.5 Upper Sheyenne River - Jump Dispersal

Affected habitat (river-miles): 244.50

	<------------(Percentage)------------>		<--------------(River-Mile Years)-------------->	
Year	Certain (a)	Expected (b)	Current Value	Present Value
0	0.00%	0.00%	0	0
1	6.67%	6.67%	16	16

2	13.33%	13.33%	33	31
3	20.00%	20.00%	49	45
4	26.67%	26.67%	65	58
5	33.33%	33.33%	82	70
6	40.00%	40.00%	98	82
7	46.67%	46.67%	114	93
8	53.33%	53.33%	130	103
9	60.00%	60.00%	147	112
10	66.67%	66.67%	163	121
11	73.33%	73.33%	179	130
12	80.00%	80.00%	196	137
13	86.67%	86.67%	212	144
14	93.33%	93.33%	228	151
15	100.00%	100.00%	245	157
Beyond (g)				5,231
Total				6,681

Section 2 Quantification of Replacement Services

	<------------(Percentage)------------>	
Year	Current Value	Present Value
5	0.0%	0.0%
6	5.0%	4.2%
7	10.0%	8.1%
8	15.0%	11.8%
9	20.0%	15.3%
10	25.0%	18.6%
11	30.0%	21.7%
12	35.0%	24.5%
13	40.0%	27.2%
14	45.0%	29.8%
15	50.0%	32.1%
16	55.0%	34.3%
17	60.0%	36.3%
18	65.0%	38.2%
19	70.0%	39.9%
20	75.0%	41.5%
21	80.0%	43.0%
22	85.0%	44.4%
23	90.0%	45.6%
24	95.0%	46.7%
25	100.0%	47.8%
Beyond (h)		1592.0%
Total		2203.1%

Section 3 Offsetting Restoration for One Organism

Lake Ashtabula - Progressive Dispersal (acres):	7,920
Lake Ashtabula - Jump Dispersal (acres):	8,160
Lower Sheyenne River - Progressive Dispersal (river-miles):	326
Upper Sheyenne River - Progressive Dispersal (river-miles):	294
Upper Sheyenne River - Jump Dispersal (river-miles):	303

Section 4 Notes

(a) Percent loss given certain invasion

(b) Percent loss given probability of successful invasion

(c) From year 2 into perpetuity

(d) From year 1 into perpetuity

(e) From year 18 into perpetuity

(f) From year 17 into perpetuity

(g) From year 16 into perpetuity

(h) From year 26 into perpetuity