Risk and Consequence Analysis Focused on Biota Transfers Potentially Associated with Surface Water Diversions Between the Missouri River and Red River Basins

Supplemental Report: Risk Reduction Captured by Water Supply Alternatives and Preliminary Analysis of Economic Consequences Associated with Biota Transfers Potentially Realized from Interbasin Water Diversion

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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 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 2005). As part of that continuing technical support effort, Reclamation requested

- a supplemental evaluation of risk reduction that may be realized by water supply alternatives and water treatment options that have been proposed to meet water demands of the Red River Valley, as those alternatives and options are characterized in the Draft Environmental Impact Statement being prepared by Reclamation as part of their National Environmental Protection Act (NEPA) compliance process, and
- a preliminary analysis of economic consequences potentially realized at Red Lake, Minnesota, if biota transfers occurred subsequent to an interbasin water diversion.

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 these concerns.

2.0 Source Water and Disinfection Options Considered in the Draft Environmental Impact Statement (DEIS)

For evaluating risk reduction potential captured in the DEIS, two general attributes of a risk reduction evaluation guided this preliminary analysis—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.

Eight alternatives considered in the Draft Environmental Impact Statement (DEIS) reflected spatial attributes of water source differently. Seven alternatives can be 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; 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 focus on supplementing existing water supplies with in-basin or imported water (supplemental alternatives) and one proposes replacing all existing water supplies with Missouri River water (replacement alternative). Brief summaries of these no action, supplemental, and replacement alternatives follow, and are derived from their more complete characterization found in Reclamation (2005a).

2.1 No-Action Alternative

The No-Action Alternative considers the future without the project and serves as the 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 same proposed service area as the action alternatives (i.e., 13 counties in eastern North Dakota plus the Minnesota cities of East Grand Forks, Moorhead, and Breckenridge). While Reclamation in their DEIS must consider other issues, e.g., costs of infrastructure and projecting water supply to 2050, our focus on risk reduction captured by the No-Action Alternative simplifies the preliminary analysis detailed in this supplemental report.

Table 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	Red River Valley Water Supply Project is not realized
	North Dakota In-basin	Water sources primarily within Red River Valley of North Dakota
	Red River Basin only	Water sources rely on available surface water and groundwater from Red River Basin of Minnesota and North Dakota
	Lake of the Woods	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	Links GDU Principal Supply Works (Snake Creek Pumping Plant, Lake Sakakawea, Audubon Lake, and McClusky Canal) to Sheyenne River via pipeline
	Missouri River import to Red River Valley	Missouri River waters conveyed to Red River Valley via pipeline
	GDU import pipeline	GDU Principal Supply Works and pipeline would convey Missouri River waters to Red River Valley
	GDU water supply replacement pipeline	Missouri River waters conveyed to Red River Valley via pipeline

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 sources, with untapped in-basin water supplies being groundwater sources for small communities and rural water systems, and purchase of groundwater and surface water irrigation rights where feasible.

2.1.1 Risk Reduction and No-Action Alternatives

From a technical perspective the No-Action Alternative is an in-basin alternative lacking any project-specific proposals for supplementing water supply to the Red River Valley. Despite "no action" being specified, future water needs will be considered and water management options within the Red River basin will be pursued between now and 2050. Under this No-Action Alternative risks of interbasin biota transfers realized because of water diversions between Missouri River and Red River basins ***directly*** linked to interbasin water diversions would be practically zero. In the absence of infrastructure needed to implement any of the Action Alternatives—such as a pipeline under a closed-conveyance scenario (see USGS 2005)—pathways linking Missouri River and Red River basins would not be complete under the No-Action Alternative. Hence, risks directly related to engineered water diversions would not be realized. Risks of interbasin biota transfers and species invasions, however, would not be eliminated. Competing pathways associated with stochastic environmental events that are relatively independent of engineered infrastructure required to satisfy water demands under the No-Action Alternative (e.g., floods, seasonal storms) may continue to yield biota exchange between Missouri River and Red River basins, as past paleoecological accounts (see Appendix 18; USGS 2005), 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 other than those captured in designed water infrastructure associated with "action alternatives" might alter biota exchange

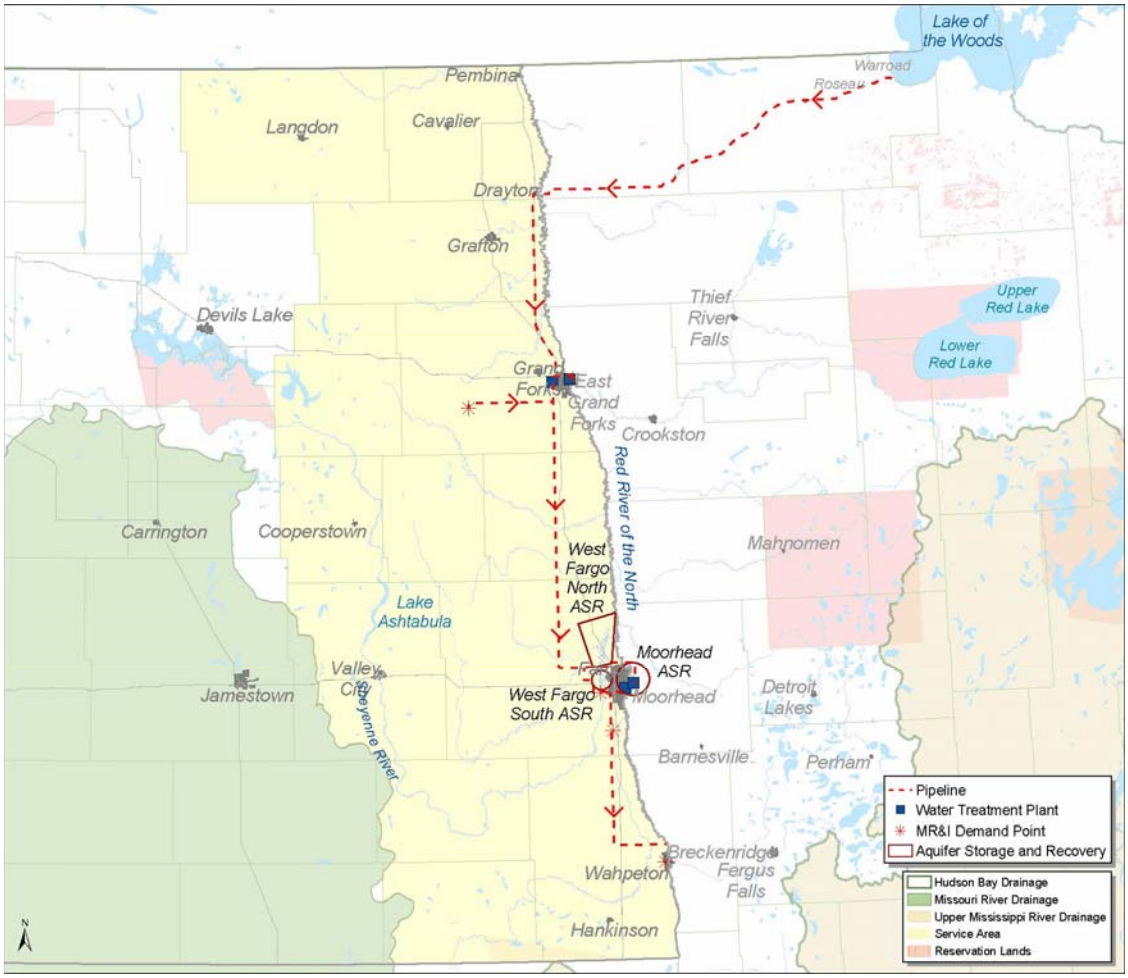
between Red River and Missouri River basins (see Kerr et al 2005; Taylor and Irwin 2004; Maki and Galatowitsch 2004 for recent publications discussing other pathways enabling biota transfers or species invasions).

2.2 In-basin Action Alternatives

North Dakota In-Basin Alternative. As 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. The alternative also would 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. Additional storage reservoirs would be needed by communities in the northern end of Red River Valley.

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. Additional storage reservoirs would need to be constructed to serve communities in the northern end of Red River Valley.

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). While water transfers from Lake of the Woods to Red River Valley require transfer of water from one sub-basin to another sub-basin within the HUC09, 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.



2.2.1 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 realized because of 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 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 and 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, 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).

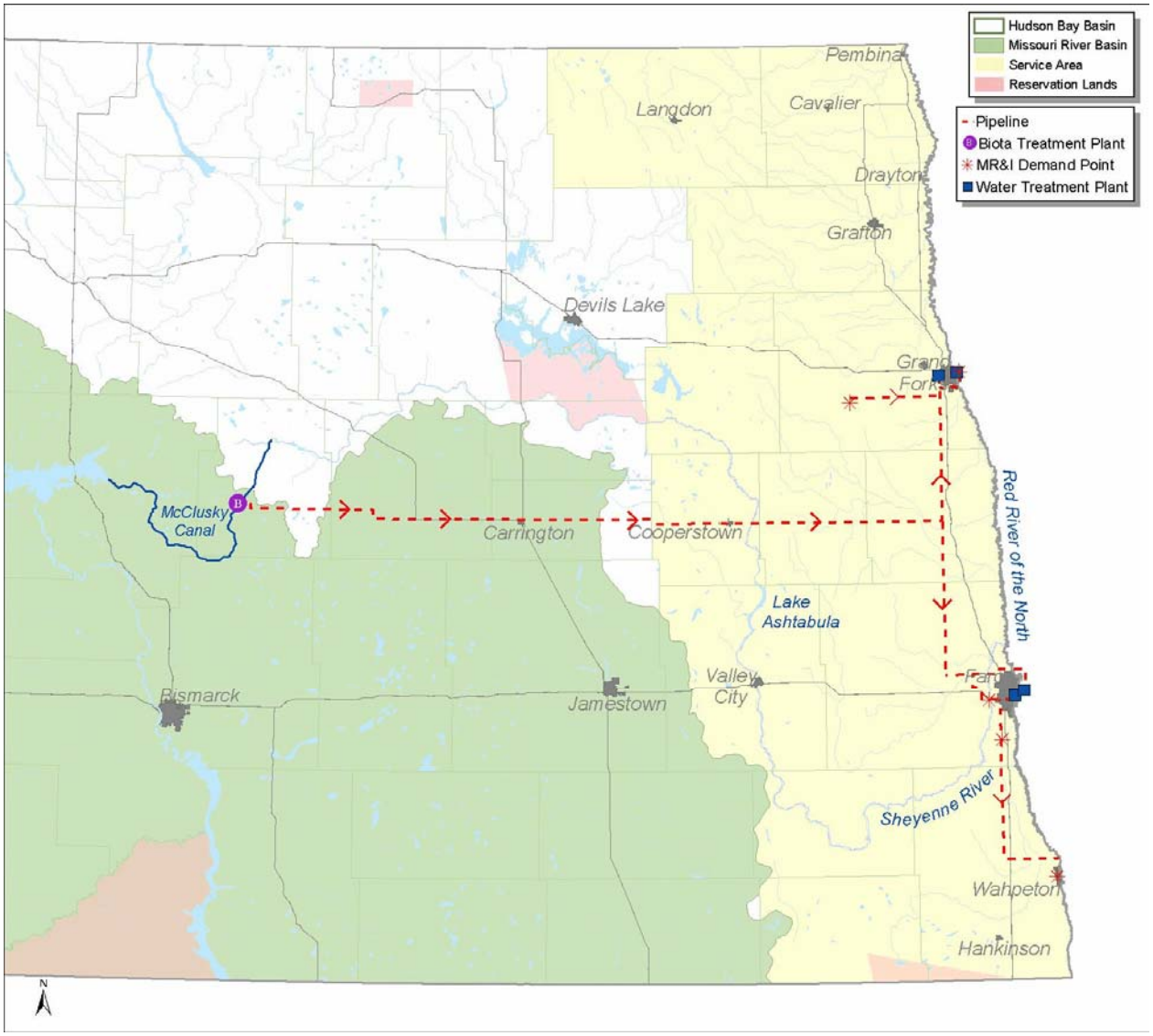
While the Lake of the Woods alternative represents a water diversion within HUC09, proposed water transfers would occur between sub-basins within HUC09 and may have risks associated with the potential completion of pathways enabling or continuing the dispersal of biota of concern presently in HUC0903 (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.

2.3 Action Alternatives Relying on Source Waters from Missouri River

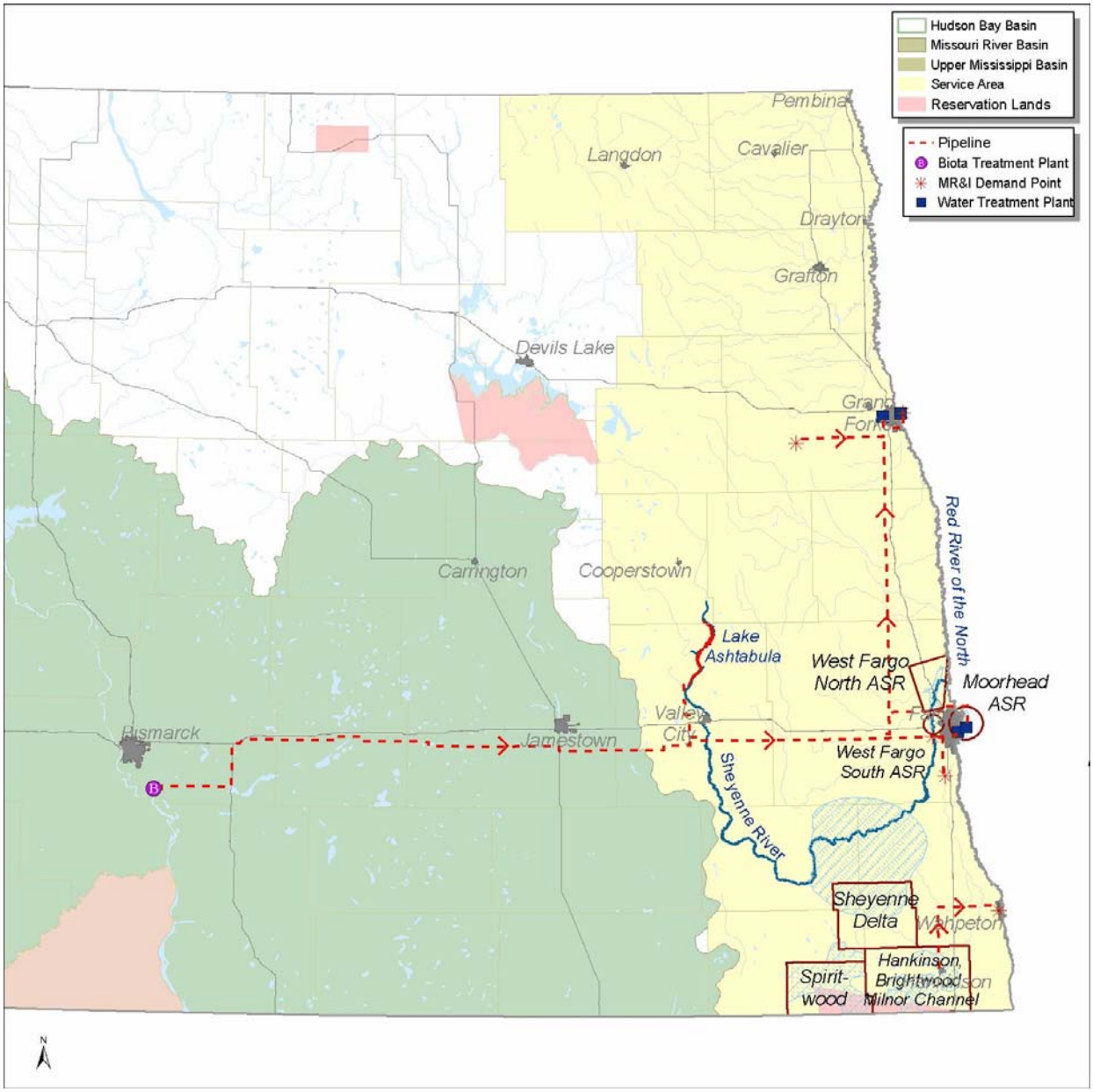
GDU Import to Sheyenne River Alternative. This alternative would supplement existing water supplies to meet future water needs with a combination of the Red River, other North Dakota in-basin sources, and import Missouri River water (Figure 2). An intake pumping plant located on McClusky Canal would rely on a conventional wet-sump pumping station, and the principal conveyance feature would be a pipeline from the McClusky Canal to the Sheyenne River about 3 miles 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. The alternative would include a biota treatment plant at the McClusky Canal intake and a pipeline to serve industrial water demands in southeastern North Dakota. The biota treatment process would use coagulation, flocculation, sedimentation, and ultraviolet disinfection (Table 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 3). An intake pumping plant located on 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. The alternative



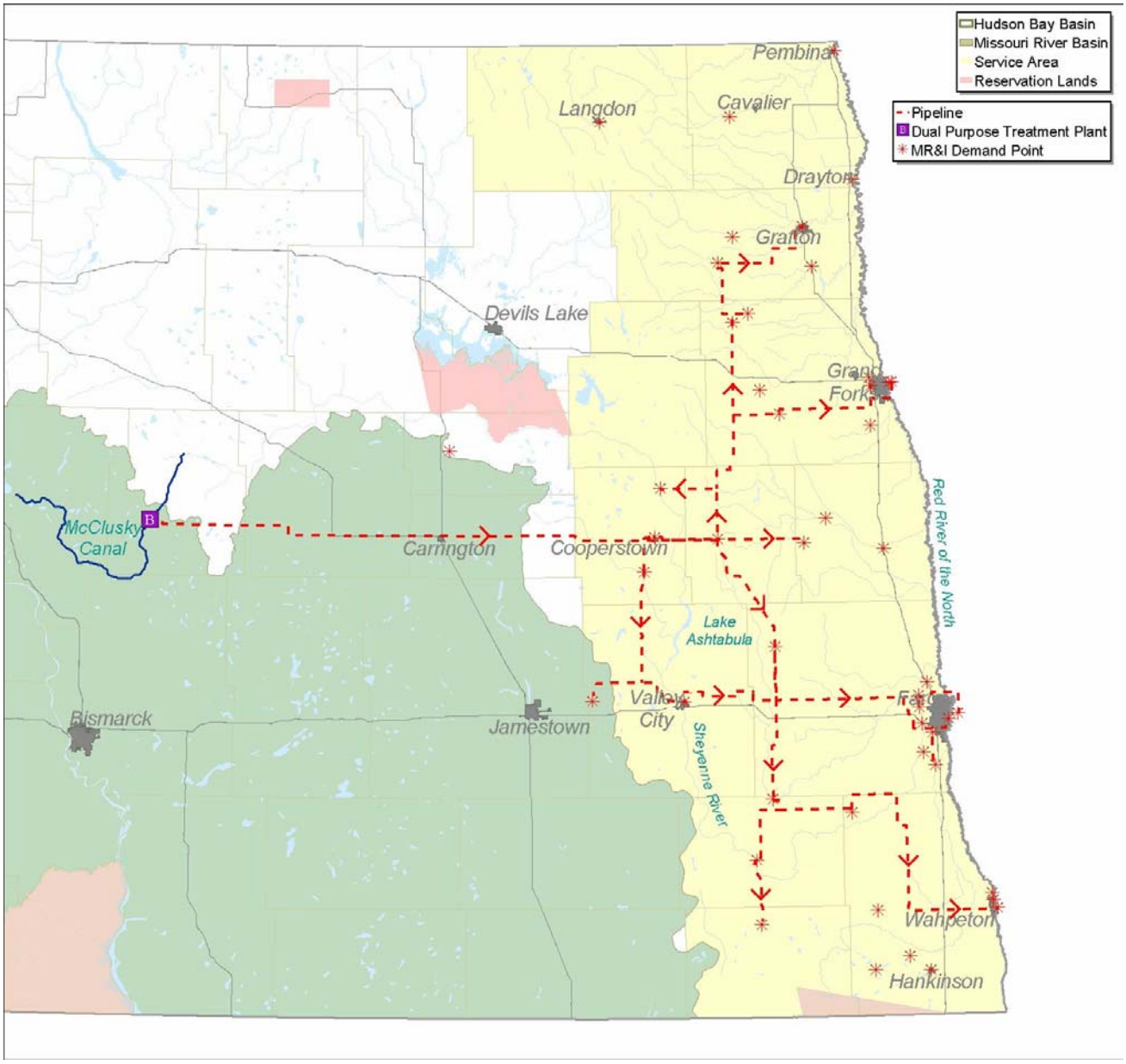
includes a biota treatment plant at the McClusky Canal and a pipeline to serve industrial water demands in southeastern North Dakota. The alternative would rely on existing storage and regulation capability of Lake Ashtabula to meet some of the downstream MR&I water demands. The biota treatment process would use coagulation, flocculation, sedimentation, and ultraviolet disinfection (Table 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 closed pipeline from the Missouri River south of Bismarck directly to Fargo and Grand Forks (Figure 4). The alternative would rely on a radial collector well system comprised of horizontal



wells for extraction of source water from Missouri River alluvial deposits and also includes a biota treatment plant at the Missouri River near Fargo (Reclamation 2005b,c). The biota treatment process would use coagulation, flocculation, sedimentation, and ultraviolet disinfection (Table 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. 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 5). 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 capacity to meet the peak-day water demand of the entire service area. 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 2).



2.3.1 Water Treatment Technologies Proposed In Action Alternatives and Their Potential to Reduce Risks Associated With Biota Transfer

As noted in USGS (2005), water diversions envisioned under the Flood Control Act of 1944 nearly 60 years ago markedly differ from those being considered as options under water

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

Water import alternative	Estimated pipeline in transfer conveyance (miles)	Biota treatment plant location	Summary of water processing incorporated into proposed biota treatment plant**					
			Coagulation	Flocculation	Sedimentation	UV disinfection	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	595	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.

management plans currently envisioned by Reclamation (2005a). Therein, and given the concerns related to biota transfers initially voiced by the International Joint Commission (IJC) in the late 1970's, in these alternatives control systems have been considered that reduce risks of biota transfers potentially associated with water diversions between Missouri River source waters and the receiving system, Red River of the North. In the absence of regulatory benchmarks specific to biota transfers and in the absence of promulgated standards specifying "acceptable risks" related to species invasions that are specified on an ecological basis, implementing interbasin water transfers in full compliance with the Safe Water Drinking Act (1974) as amended (including amendments promulgated in 1996) would bring to resource management discussions a system of control technologies that are effectively 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 (2005).

Overview of Water treatment control systems as a risk reduction tool. Various control technologies have been developed to assure water disinfection is achieved and limited as a major factor in disease outbreaks and epidemics associated with drinking water. These control technologies range from chemical and physicochemical treatments (e.g., chlorination and chloramination, UV disinfection) to physical barriers acting as filters (e.g., pressure-driven 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, yet regardless of configuration, 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 unintended byproducts which may pose risks consequent to interaction with naturally-occurring materials in the water (see, e.g., Percival et al 2004, Letterman 1999).

Chemical treatments: Chlorination, Chloramination, and Chlorine dioxide.[1]

[1]See USGS (2005) for expanded discussion of chlorine, chloramine, and chlorine dioxide

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 pressure-driven membrane systems). More often than not, combined water treatment technologies are applied to the water disinfection process.

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.

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disinfection and technical references supporting that discussion.

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.

Chloramine is use 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* 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 3 to illustrate the range of disinfection realized under various technologies (see Connell 1996, Haas 1999 and White 1999 for discussion).

Table 3. Examples of contact times (mg/L x minute) for various chlorine-based disinfectants (Connell 1996, Haas 1999, White 1999, Jacangelo et al. 2002).

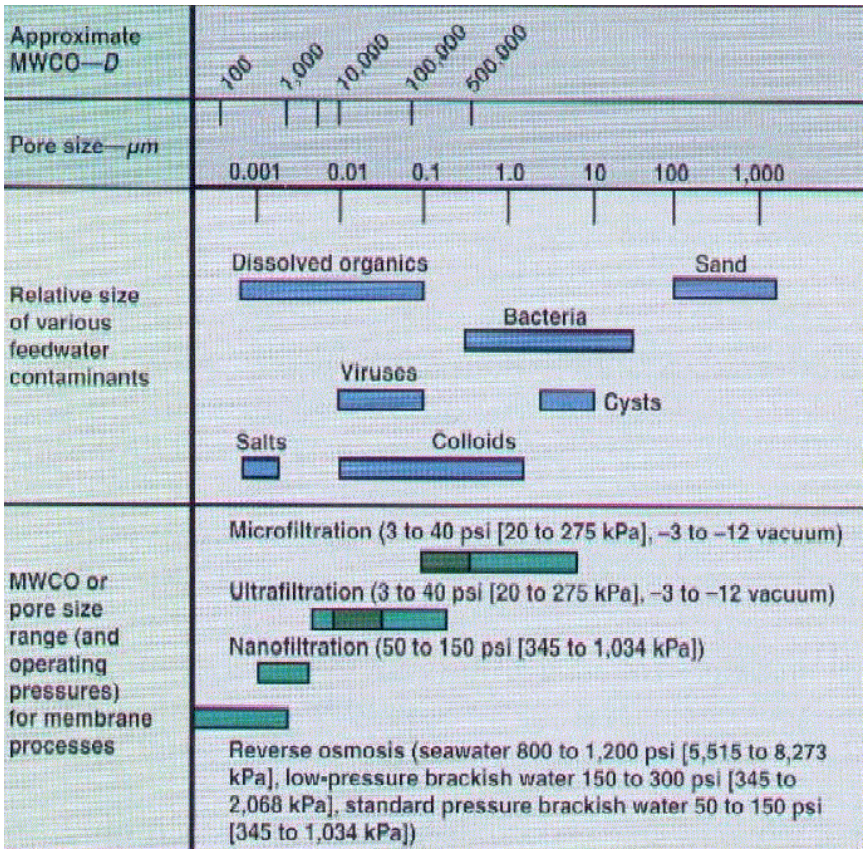
Indicator	Chloramines	Chlorine	Chlorine Dioxide
Giardia 0.5 log inactivation pH 6-9, 5°C	340-380	15-50	4.0-6.0
Viruses 2 log inactivation pH 6-9, 5°C	825-900	4-7	5.0-6.0
Cryptosporidium pH 7, 25°C	72002 log inactivation	72001 log inactivation	781 log inactivation

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).

Membrane filtration.[2] Membrane filtration technology has been increasingly applied to water treatment problems. The range of membrane technologies that have become 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

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

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). 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 briefly considered: microfiltration, ultrafiltration, and nanofiltration (Figure 6; graphic after AWWA).



Microfiltration is characterized as a solid-liquid separation process with a molecular weight cut off between between 0.1 μm and 10 μm (Figure 6). Microfiltration reduces the

passage of suspended particles, high-molecular weight lipids and fats, macromolecules, bacteria and protozoa (although *Cryptosporidium* spp. and *Giardia* spp. or their cysts may not be removed completely). 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 6). 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 6). 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 demineralisation, which tends to yield potable water from slightly brackish water or humic-stained surface water(see Mallevialle 1996, Duranceau 2001).

***Cryptosporidium*.** One factor that is likely to influence the choice of primary disinfectants is *Cryptosporidium* which may be considered an indicator of disinfection-resistant biota that challenge water treatment efforts. Chlorine has not been demonstrated as being sufficient in treating *Cryptosporidium*, especially once the organisms have encysted. However, other water treatment processes, e.g., adequate filtration provide protection from the disease agent. In some areas with poor water quality, a combination of disinfection technologies may be necessary to provide disinfection 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).

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 December 8, 2004). 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 December 8, 2004). Groundwater, although filtered by natural processes, is often susceptible to microbial contamination, especially in rural communities, and source waters may need disinfection as part of the treatment process. Increasingly, sources of drinking water dependent on groundwater have been found vulnerable to microbial contamination, including indication of fecal contamination from tests for total coliform bacteria, *E. coli*, coliphage and human viruses (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).

Surface Water Treatment Rule. 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 further 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 (LT2ESWTR) focus on a *Cryptosporidium* disinfection requirement.

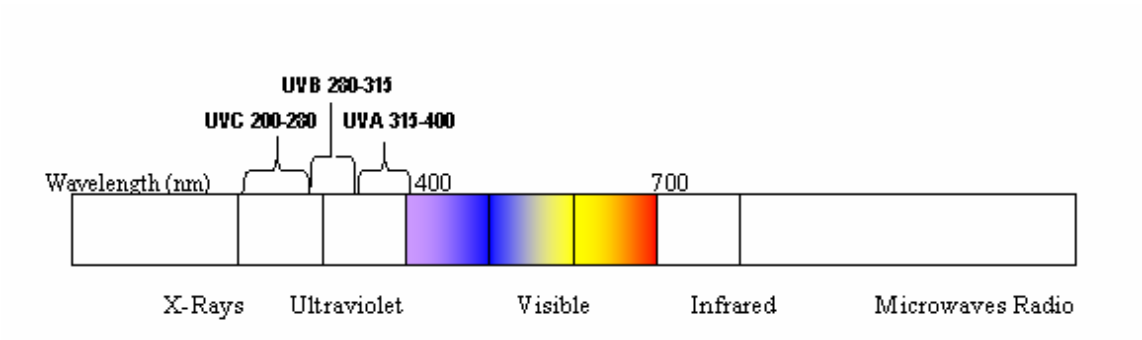
UV Disinfection of Drinking Water.[3] Given the water treatment technologies proposed as part of the Action Alternatives, and in view of the "Best Available Technologies" being considered as part of regulatory guidance, UV disinfection technologies are elaborated beyond those brief materials in USGS (2005), Appendix 12 with a review of supporting literature cited therein (e.g., Percival et al 2004; Mackay et al. 2001; Malley et al. 2004; Snicer et al. 2000).

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, given the 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 focused on UV disinfection have demonstrated its effectiveness for inactivating *Cryptosporidium* and *Giardia* at low to medium UV "doses" (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" for UV for *Giardia*, so chlorine doses can be lowered to meet DBP standards.

Use of ultraviolet (UV) light to disinfect water of waterborne pathogens relies on the germicidal properties of a narrow range of the UV spectrum (Figure 7). In sunlight, UV spectrum

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

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 if not killed and DNA repair is not completed, UV-exposed microorganisms do not replicate and thrive (see, e.g., McKey et al 2001, Jacangelo et al 2002).



UV dose measured in microwatt-seconds per square centimeter[4] 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 μW-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 μW-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. UV systems can also be coupled with a 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.

[4]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.

UV treatment alone offers no residual disinfection, and 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 total suspended solids (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 jargon. To assure optimal performance, pre-treatment of incoming source waters may be required, including filtration, e.g., through a 5-micron filter, to reduce or remove iron and water hardness, as well as remove sediment which potentially provides habitat for microorganisms.

2.3.2 Risk Reduction and Action Alternatives Relying on Missouri River Source Waters

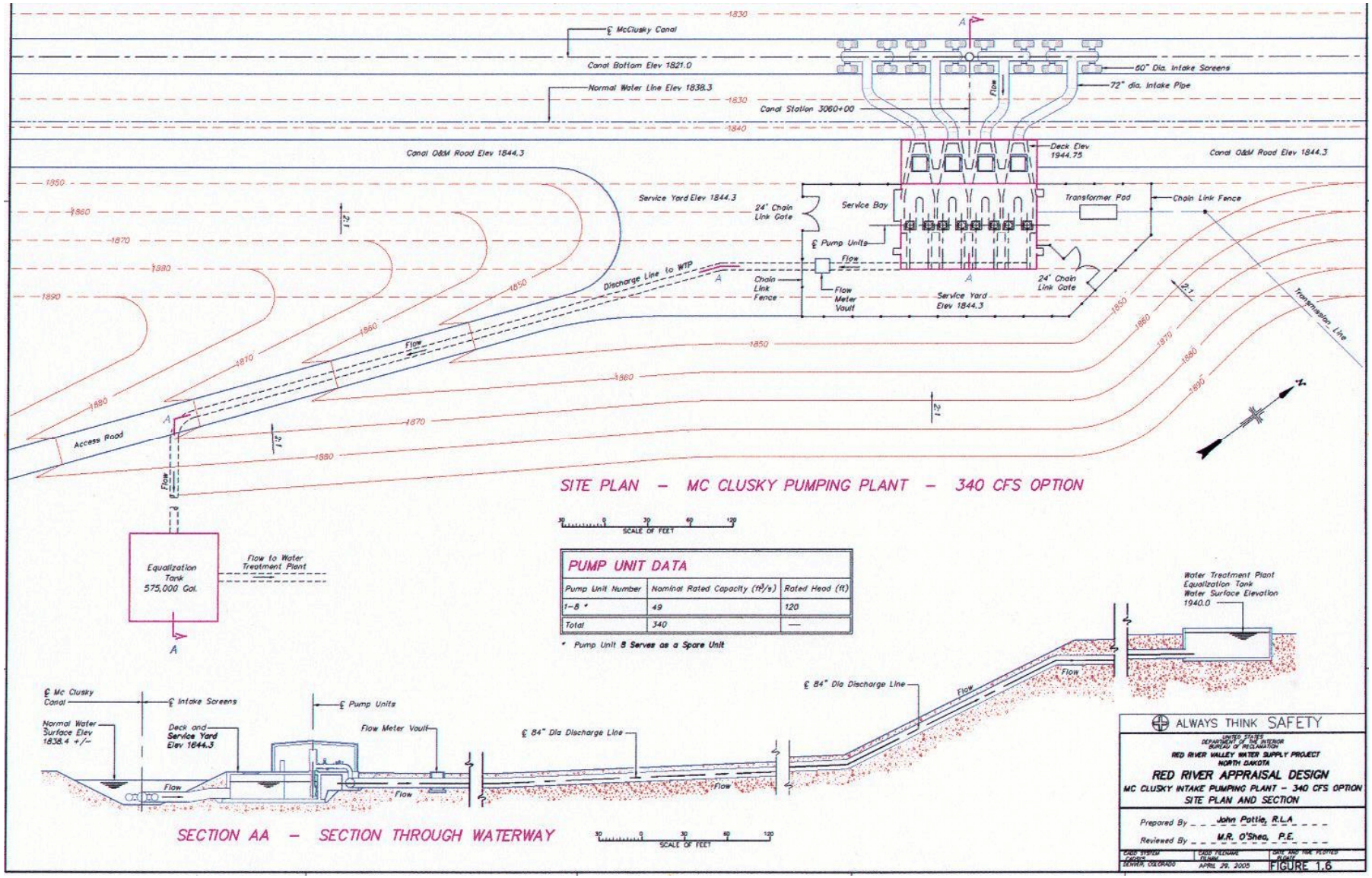
Analysis of risk reduction related to interbasin water diversions considered as Action Alternatives in the DEIS may be simplified by considering (1) spatial attributes of proposed biota-water treatment plant; that is, where treatment occurs, and (2) physical and chemical attributes that characterize the treatment process and conveyance infrastructure.

Source Waters Withdrawal, Distribution Infrastructure and Action Alternatives in DEIS. Within the spatial context of risk, each of the action alternatives identified and characterized in the DEIS have incorporated a biota-water treatment plant in the Missouri River basin either near the McClusky Canal or Bismarck, North Dakota. Spatial attributes of risks for these action alternatives is largely a wash, and a focus on how water is withdrawn from sources may be considered. 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. For alternatives targeting source waters at McClusky Canal, a "wet-sump" pumping plant as been proposed for an open-water intake (Reclamation 2005b, Figure 8). In contrast, for the Missouri River Import to Red River Valley Alternative, Reclamation has proposed using horizontal wells (Figure 9) in a radial collector-well design (Figure 10 and Figure 11) to withdraw the water from Missouri River source by placing wells in the alluvium under the direct influence of the river. In this application, horizontal 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 the horizontal well; 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 horizontal wells, the quality of water delivered to the biota-water treatment plant proposed for this action alternative may be improved. Surface water systems targeted for withdrawal may also have greater variation in water quality due to seasonal flow volumes in the supply source, and the filtration and potential for chemical contaminant attenuation may reduce water treatment costs, e.g., number of chemical treatment processes, required of product water.

Buried pipe. Buried pipe has been identified in the preliminary construction specifications for the transmission system briefly characterized in Action Alternatives currently included in the DEIS. Miles of buried pipe are required of each alternative—in-basin and between Missouri River and Red River basins—and the extent of piping involved depends on the design features of any particular alternative, ranging from a low of approximately 130 miles to a high of approximately 595 miles for the GDU Import to the Sheyenne and GDU Supply Replacement Pipeline, respectively (Table 2). While the transmission system involved in the GDU Supply Replacement Pipeline has a configuration that resembles a distribution system more than a only 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

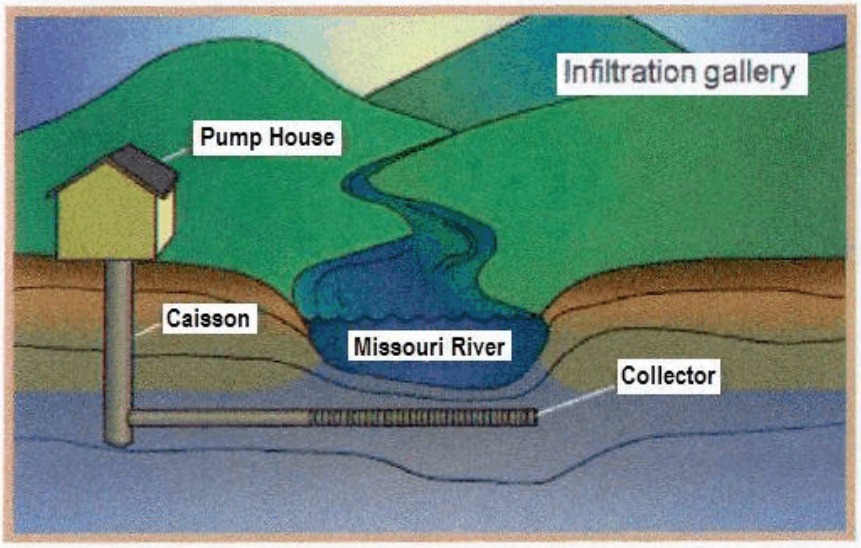
Lake Ashtabula serves as a storage-regulating reservoir in Action Alternatives except the GDU Pipeline Alternative. GDU Pipeline Alternative directly terminates at existing distribution nodes



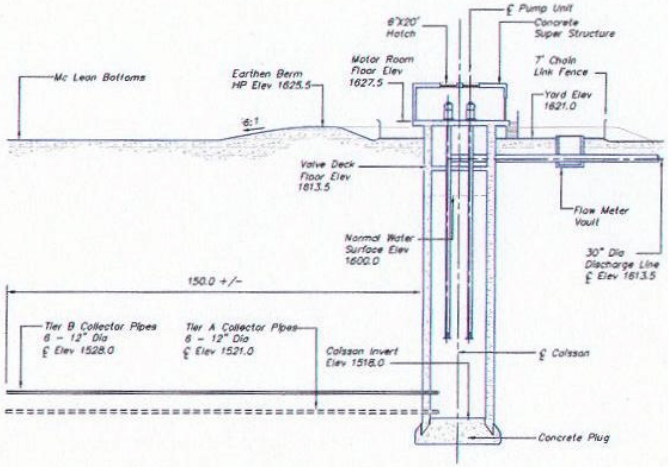
PUMP UNIT DATA

Pump Unit Number	Nominal Rated Capacity (ft^3/s)	Rated Head (ft)
1–8 *	49	120
Total	340	—

* Pump Unit 8 Serves as a Spare Unit

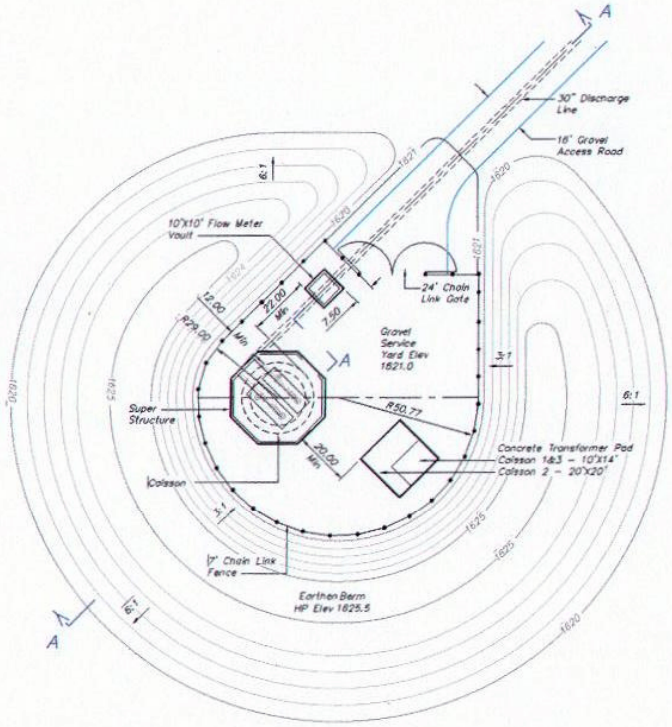


in, e.g., municipalities in Red River Valley. Regardless of the differences and similarities in these preliminary transmission system designs, buried pipe brings well-characterized past performance in water transmission and distribution networks. As a result, risks associated with buried pipelines and 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.



SECTION AA – SERVICE YARD AND TYPICAL CAISSON

SCALE OF FEET



SERVICE YARD SITE PLAN

TYPICAL FOR ALL CAISSONS

SCALE OF FEET

PUMP UNIT DATA		
Pump Unit Number	Nominal Rated Capacity (ft^3/s)	Rated Head (ft)
1&2	15	225
Total	30	

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

RED RIVER VALLEY WATER SUPPLY PROJECT
NORTH DAKOTA

RED RIVER APPRAISAL DESIGN

MC LEAN BOTTOMS INTAKE PUMPING PLANT
CAISSON SECTION AND YARD SITE PLAN

Prepared By John Pottle, R.L.A.

Reviewed By M.R. O'Shea, P.E.

CAD TYPE: CADD
DENVER, COLORADO

CADD FILENAME: FIGURE
APRIL 29, 2005

DATE AND TIME PLOTTED: PLOT

FIGURE 1.3

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. A simple summary of threats to a water transmission and distribution system are included in Table 4 adapted from EPRI (2001). Failures of buried pipe stem from a set of potentially interrelated attributes of the transmission and distribution systems and their component parts. These attributes may be time independent, time dependent, or related to pipe materials independent of the system of which they are part (e.g., reinforced concrete pipe has physical attributes the influence its life span independent of its use). For example, buried pipelines are subject to significant degradation from various internal and external corrosion mechanisms leading 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 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), buried pipe will generally be placed 3–6 feet below ground surface (BGS) to prevent freezing, and 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), 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., e.g., http://www.asce.org/instfound/codesandstandards.cfm, last accessed August 31, 2005). For example, transmission

Table 4 General listing of concerns related to failure analysis for buried pipelines (adapted from EPRI 2001).

Time-dependent 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

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

Fatigue (pipe material aging)

- Pressure cycling
- Thermal cycling

Heavy fouling/clogging (deposition on pipe inner walls)

Time-independent Attributes

Mechanical Damage

- Outside party (e.g., other vendors)
- Installation
- Previously damaged

Incorrect Operations

- Operator error
- Incorrect operating procedure
- Over pressurization

Outside Force

- Earth movements
- Heavy rain, floods

Materials Attributes

Manufacturing Related

- Defective Pipe Seam
- Defective Pipe
- Wrinkle bend or buckle
- Stripped threads/coupling failure

Welding Fabrication Related

- Defective pipe girth weld
- Defective long seam weld

Equipment

- Gasket O-ring
- Control/relief equipment malfunctions
- Seal/pump packing failure
- Miscellaneous

and distribution lines may be constructed of a variety of materials, but must withstand, e.g., internal and external pressures, including “water hammer” and be resistant to corrosion. Under a variety of specifications, materials for pipeline construction include cast iron and ductile iron of several standard thicknesses to handle different pressure loads. For buried pipe, push-on joints are commonly used, e.g., for ductile or cast iron pipe, to provide a range of flexibility which reduces breaks associated with earth movements such as settling or creep. Reinforced concrete pipe (RCP) consist of a steel pipe wrapped with wire and embedded in a concrete sleeve, and are commonly used in large transmission or main distribution lines, having diameters up to 12 feet. Polyvinyl chloride (PVC) and High Density Polyethylene (HDPE) are increasing found in distribution networks wherein light-weight materials having good hydraulic characteristics, yet relatively small capacity (e.g., diameters up to 2 feet) are required in a design. 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.

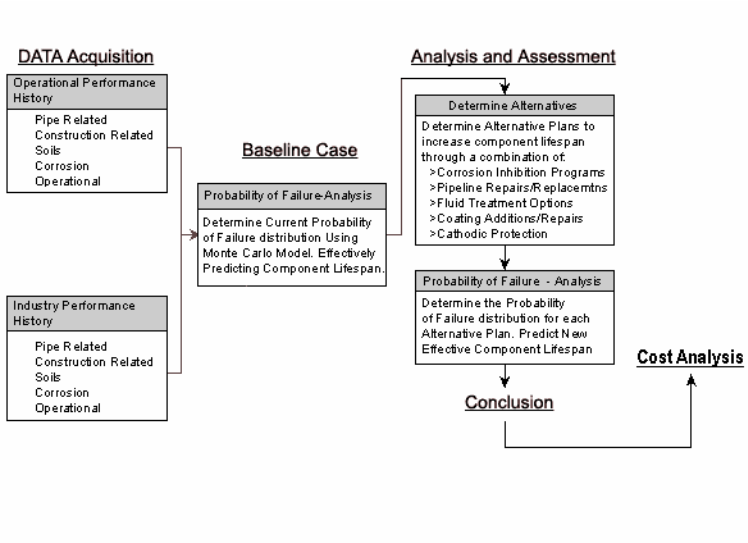
Water management agencies use their transmission and distribution systems to deliver high quality water in the face of breaks, corrosive deterioration, and other forces affecting system integrity. These management issues will confront resource managers considering proposals for waters to be transferred via pipelines proposed under the current set of Action Alternatives. Water transferred via pipeline from either the open-water intake and biota-treatment plants at McClusky Canal or the radial array of horizontal collecting wells and biota-treatment plant near Bismarck will be a 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, but should be incorporated into long-term management plans for the water system regardless the alternative selected. 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). Once an alternative is selected for addressing the water needs of the Red River Valley, engineering designs can go beyond industry-wide experience, e.g., relying on existing information on pipe breaks (e.g., Deb et al. 1995), and gather system-specific data that reflects failure rates of systems or system components in order to develop reliability estimates for the system to be built to deliver water to the area of concern. 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 (Figure 12).

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 realized as events collateral to an interbasin water diversion. Reclamation had considered a range of biota-water treatment options in parallel with their identifying alternatives considered in the DEIS (see Reclamation 2005c). As

presently identified and characterized in the DEIS being prepared by Reclamation, disinfection is a key component in each Action Alternative (Table 2). Action Alternatives characterized in the DEIS provide a range of water treatment technologies available to the task of reducing risks related to biota transfers realized consequent to a interbasin water diversion. Each of the Action Alternatives includes a conventional pretreatment that involves coagulation, flocculation, and sedimentation.



Coagulation-Flocculation-Sedimentation and Beyond. 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 headed to the treatment facilities will pass through a series of conventional chemical treatments—coagulation-flocculation-sedimentation—intended to remove suspended solids, some dissolved chemical substances (e.g., iron, calcium, magnesium), and some impurities from raw waters.

These three conventional treatment steps reduce or remove suspended and dissolved solids which improves the appearance and taste of drinking water, reduces or removes some of the chemical and 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 and hardness 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.

Once intake water has passed through conventional treatment, various options are available to engineering design, including filtration, disinfection, and water softening. Filtration options range widely, e.g., media filtration, often times sand or other granular materials through 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.

Disinfection and Risk Reduction. Appendix 11 and Appendix 12 in USGS (2005) and references provided therein provided a brief background on disinfection characterization and various chemical and physical options currently applied to water treatment requirements pursuant to regulatory requirements, e.g., SDWA and its amendments. For example, under the regulatory auspices of the SDWA as amended, EPA has regulations that 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 *Giardia 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). 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, and if an organism has a high resistance to a certain disinfectant, contact time will be greater than for an organism with a low resistance.

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 menu 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 incorporated into system's design (e.g., microfiltration). 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 specified 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).

Table 5 summarizes the initial evaluation of "risk reduction credits" that are associated with each of the Action Alternatives. For this analysis the water transfer system was considered as discrete compartments in a categorical analysis (see Appendix 4, USGS [2005]) wherein Action Alternatives were scored for, e.g., means of water withdrawal, local 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).

Risk reduction credits were assigned to each compartment within the system as proposed in the DEIS, and reflected assigned values for ordinal data as indicated (see Table 4 footnotes). Assigned values were simple binary scores weighted so increasing value captured greater reduction in risks, e.g., 0 was assigned to open-water withdrawals at McClusky and 1 was assigned to withdrawals from horizontal wells proposed for Missouri River pumping plan near Bismarck. Similarly, if proposed biota-treatment plant was located in Missouri River basin, an assigned risk reduction value of 1 was scored for that compartment within the system relative to

Table 5 Preliminary evaluation of risk credits captured by each Action Alternative.

Risk-reduction credits for Action Alternatives involving an interbasin water diversion*												
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]**		**Risk of pipeline failure[6]**	**Total risk credits**
			Coagulation	**Flocculation**	**Sedimentation**	**UV disinfection**	**Lime softening**	**Microfiltration**	**Open-water**	**Pipeline**		
GDU Import to Sheyenne River	0	1	1	1	1	1	0	0	0	0	3	8
GDU Import Pipeline	0	1	1	1	1	1	0	0	1	1	2	9
Missouri River Import to Red River Valley	1	1	1	1	1	1	0	0	1	2	1	10
GDU Water Supply Replacement Pipeline	0	1	1	1	1	1	1	1	1	3	0	11

*see text for discussion

[1] 0=open-water withdrawal; 1=horizontal well

[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

the Red River basin alternative valued at 0. For pre-treatment (defined as serial steps involving coagulation-flocculation-sedimentation), scores were assigned as 0 for no pre-treatment and 1 for pre-treatment present. Given the current proposed designs, other disinfection measures were also incorporated into the analysis as compartments beyond pretreatment, and were scored as 0, not included in proposed design, or 1, included in proposed design. Method of water transfer—open-water *v.* closed conveyance via pipeline—was also scored as a simple binary-valued attribute wherein 0 risk reduction credit was assigned to systems having open-water conveyance—regardless of extent—designed in the transmission network, and 1 risk reduction credit was assigned to systems completely contained throughout the transmission network. In contrast to these binary-valued attributes of proposed Action Alternatives, extent of transmission pipelines as compartments within the control system were ordered attributes, ranging from values of 0 associated with least risk reduction to 3 associated with greatest risk reduction.

Following the assignment of risk reduction credits to each compartment within Action Alternatives, component scores were summed to yield total risk reduction credits. On the basis of this categorical analysis, the current menu of Action Alternatives yielded a range of risk reduction credits potentially realized with each system—in ascending order, GDU Import to Sheyenne River < GDU Import Pipeline < Missouri River Import to Red River Valley < GDU Water Supply Replacement Pipeline. Given the similarities in proposed designs for each Action Alternative, the analysis of risk reduction relative to preliminary design suggests that each system's risk reduction credits might provide sufficient margin for accepting risks associated with biota transfers consequent to any system's failure, if costs were incorporated into future engineering design analysis. Similarly, risks associated with, e.g., transmission pipelines illustrate the reciprocal character of engineering risks as currently captured in this risk reduction analysis—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 captured by pipeline breaks, since the occurrence of pipe breaks would be

greatest in the system designed with most pipeline miles, provided risks within any given transmission network and among alternative transmission systems were identical (see note below regarding uncertainties).

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. While the current analysis of risk reduction acknowledges differences among Action Alternatives, the summary findings reflect 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). Future engineering risk analysis may refine this assumption to capture differences across pipe materials, locations, and component parts of the transmission system, e.g., control valves, pipe configurations.

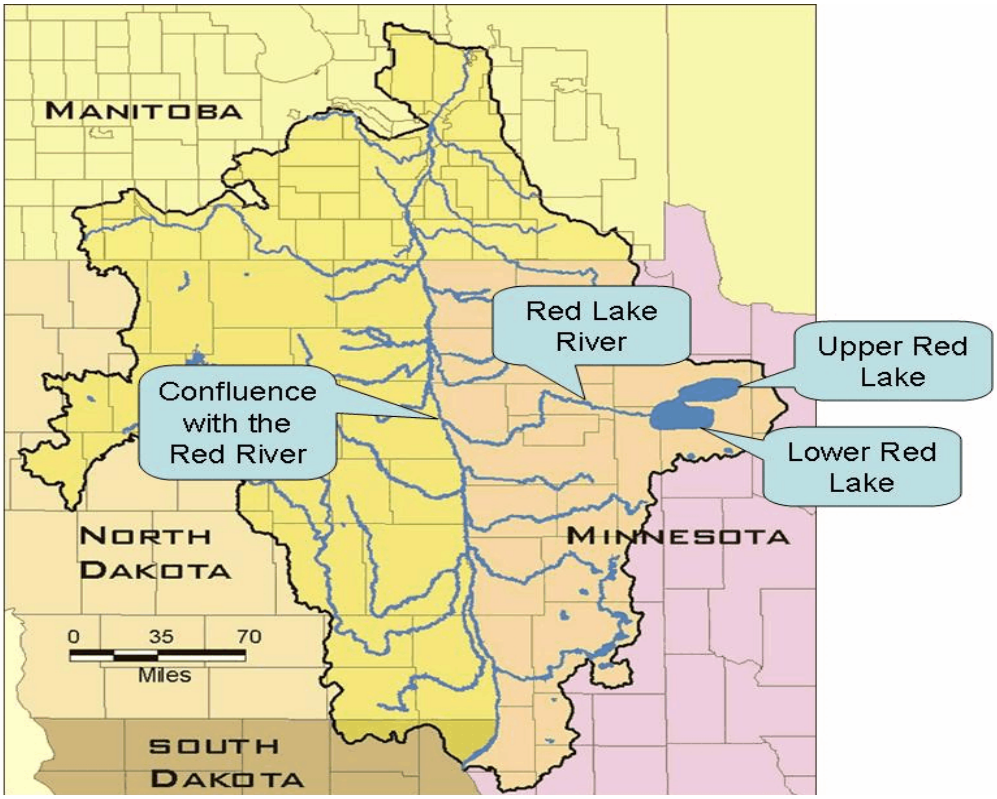
2.4 Conclusions: Risk Reduction and Action Alternatives

The Action Alternative providing greatest risk reduction as viewed through this preliminary analysis was the 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. For example, if costs were included in this analysis, as would likely be reflected in an engineering cost-benefit analysis, the Missouri River Import to Red River Valley may provide sufficient risk reduction in the absence of microfiltration, given withdrawal of intake water is accomplished using a radial collective of horizontal wells at the Missouri River source. Although relatively short in duration, the open-water conveyance of treated waters via the Sheyenne River adversely affect 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.

USGS (2005) observed that 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 (USGS 2005) suggested that risks of biota transfers under such a controlled, closed-conveyance scenario would range from 10^{-6} to 10^{-9} and less than 10^{-9}. 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—but the alternatives considered in this analysis 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. 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 me minimized.

3.0 Red Lakes and Red Lake River Consequences



US Geological Survey (2005) presents a consequence analysis of biota transfer risks that are potentially associated with interbasin water transfers 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. This supplemental report extends that analysis to include the Lower and Upper Red Lakes and the Red Lake River. The Lower and Upper Red Lakes are located in northern Minnesota and are drained by the Red Lake River, which joins the Red River at East Grand Forks, Minnesota (Figure 13). All of the Lower Red Lake and approximately 55 percent of the Upper Red Lake lie within the Red Lake Indian Reservation.

This supplemental analysis uses the habitat equivalency analysis (HEA) methodology employed by US Geological Survey (2005) to rank the potential consequences for the Lower and Upper Red Lakes and the Red Lake River relative to those already estimated for the Red River and Lake Winnipeg. The results of this analysis indicate 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. Given those results, the conclusion in US Geological Survey (2005) that the majority of the potential consequences from risks of biological invasion would likely occur in Lake Winnipeg continues to hold.

3.1 Habitat Equivalency Analysis: Model Estimation

This supplemental analysis uses the same HEA model developed in US Geological Survey (2005). For purposes of this analysis, the Lower and Upper Red Lakes are treated as a single habitat that is defined as the 260,000 acres of combined surface area (Dokken 2000). This treatment may yield an overestimate of potential consequences since the narrow channel connecting the two lakes may impede the spread of water-born invasive biota while no such impediment is modeled in the HEA. The Red Lake River habitat is defined as its 193 river-miles from the Lower Red Lake Dam to where it joins the Red River at East Grand Forks, Minnesota (Minnesota Department of Natural Resources 2005). The consequences of risk are estimated separately for these two habitats.

Biota dispersal methods and invasion rates similar to those used in US Geological Survey (2005) are used in this supplemental analysis. The *progressive* dispersal method assumes a linear, geographically incremental advancement of a biological invasion. A progressive dispersal in the Red Lake River is assumed to begin at the confluence with the Red River and to progress at a constant rate of advancement toward the Lower Red Lake. In the Lower and Upper Red Lakes, a progressive dispersal is similarly assumed to begin at the Lower Red Lake Dam and to progress incrementally toward the furthest extent of the combined lake habitat at a constant rate.

The *jump* dispersal method is represented in this supplemental analysis by an instantaneous introduction of a biological invader into the combined Lower and Upper Red Lakes habitat. In this scenario, a progressive invasion of the combined lake habitat is assumed to begin at the same time that a progressive invasion of the Red River is assumed to begin in US Geological Survey (2005).

The rates of advancement of a biological invasion are assumed to range between 1.55 and 15.5 miles per year (*ibid.*). Accordingly, a *slow* invasion would traverse the Red Lake River in

124 years (193 river-miles divided by 1.55 miles per year).[5] Assuming a circular shape, the combined 260,000-acre Lower and Upper Red Lakes habitat would have a diameter of 22.8 miles. Given that diameter, a slow invasion would require 14 years to traverse the combined lake habitat (22.8 miles divided by 1.55 miles per year). Alternatively, a *fast* invasion would require 12 years to traverse the Red Lake River (193 river-miles divided by 15.5 miles per year) and one year to traverse the combined lake habitat (22.8 miles divided by 15.5 miles per year). After these habitats have been traversed by biological invasions, the resulting ecological service losses are assumed to continue into perpetuity.

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 US Geological Survey (2005) are used in this supplemental analysis. 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 for the supplemental analysis. This is the same discount rate used in US Geological Survey (2005).

This HEA was 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).

[5] All invasion times were rounded down to the nearest whole year.

The results of those HEA calculations are presented in Table 6. Detailed HEA calculations are presented in Appendix 1.

Table 6. Offsetting Restoration for a Single Representative Invasive Organism.

Red Lake 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	0.00000000398	0.000000186
Low	1.00E-06	7.6	0.00000398	0.000186
Moderate	1.00E-03	3.7	0.00398	0.186
High	1.00E-02	1.7	0.0398	1.86
Very High	1.00E+00	0.0	3.98	186
Weighted Average			0.00	0.04

Lower and Upper Red Lakes - Jump Dispersal				
			----Offsetting Restoration----	
Risk Category	**Probability of Successful Invasion**	**Percent Outcomes***	**Slow Invasion (Acres)**	**Fast Invasion (Acres)**
Very Low	1.00E-09	87.0	0.000327	0.000393
Low	1.00E-06	7.6	0.327	0.393
Moderate	1.00E-03	3.7	327	393
High	1.00E-02	1.7	3,270	3,930
Very High	1.00E+00	0.0	327,000	393,000
Weighted Average			67.71	81.38

Lower and Upper Red Lakes - Progressive Dispersal				
			----Offsetting Restoration----	
Risk Category	**Probability of Successful**	**Percent Outcomes***	**Slow Invasion (Acres)**	**Fast Invasion (Acres)**

	Invasion			
Very Low	1.00E-09	87.0	0.000000423	0.000205
Low	1.00E-06	7.6	0.000423	0.205
Moderate	1.00E-03	3.7	0.423	205
High	1.00E-02	1.7	4.23	2,050
Very High	1.00E+00	0.0	423	205,000
Weighted Average			0.09	42.45

*The same probabilistic outcomes determined by US Geological Survey (2005) were used in this analysis.

The risks of successful biological invasion were not quantified specifically for the Lower and Upper Red Lakes or for the Red Lake River. Rather, the same probabilistic outcomes determined by US Geological Survey (2005) (Figure 1 in Section 4) were used in this supplemental analysis. The use of these probabilistic outcomes may yield an overestimate of potential risk consequences since the westward flow of the Red Lake River into the Red River presents an opposing force to the movement of water-born invasive species. These probabilistic outcomes were incorporated in Table 6 by calculating the average of the HEA results for the different risk categories weighted by their respective percentage outcomes from US Geological Survey (2005). 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 14, are analogous to those made in US Geological Survey (2005) for the Red River and Lake Winnipeg.

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 I-94 bridge on the Red River and then progress incrementally to the confluence with the Red Lake River. That stretch of the Red River is 157.4 miles (US Army Corps of Engineers, 2004), and would require 101 years for a slow invasion to traverse (157.4 river-miles divided by 1.55 miles per year) and 10 years for a fast invasion (157.4 river-miles divided by 15.5 miles per year). After the biological invasion has reached the confluence with the Red Lake River, it would then progress incrementally to the Lower Red Lake, and then progress incrementally throughout the combined Lower and Upper Red Lakes habitat. That is, the potential invasions of the Lower and Upper Red Lakes by all 31 species of concern are assumed to begin only after their progressive invasions up the Red River and through the Red Lake River have been completed. In this supplemental 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 relevant stretch of the Red River, the Red Lake River, and the Lower and Upper Red Lakes.

1 Jump - 30 Progressive: There is one jump dispersal event in this scenario. One species of concern is assumed to begin its progressive invasion of the combined Lower and Upper Red Lakes habitat at the same time that it begins its progressive invasion of the Red River at the I-94 bridge.

10 Jump - 21 Progressive: There are ten jump dispersal events in this scenario. Ten species of concern are assumed to begin their progressive invasions of the combined Lower and Upper Red Lakes habitat at the same time that they begin their progressive invasions of the Red River at the I-94 bridge. In this supplemental analysis, this dispersal scenario yields the highest levels of risk consequences (in present value terms) since it assumes the greatest number of species that jump instantaneously to the Lower and Upper Red Lakes.

Figure 14. Dispersal Scenarios Included in the Supplemental Analysis.

The aggregations to the 31 species of concern are presented in Table 7. 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 the Lower and Upper Red Lakes given a slow invasion and the 1 - Jump - 30 Progressive dispersal scenario (70.4 acres in Table 7) was obtained by taking 1 times the offsetting restoration for a single representative invasive organism given a slow invasion and a jump dispersal (67.71 acres in Table 6) plus 30 times the offsetting restoration for a single representative invasive organism given a slow invasion and a progressive dispersal (0.09 acres in Table 6).

Table 7. Offsetting Restoration for 31 Biota of Concern.

	------Offsetting Restoration*------	
	Red Lake River	**Lower and Upper Red Lakes**
Dispersal Scenario	**(River-Miles)**	**(Acres)**
Slow Invasion		
0 Jump - 31 Progressive	0.0	2.8
1 Jump - 30 Progressive	0.0	70.4
10 Jump - 21 Progressive	0.0	679.0
Fast Invasion		
0 Jump - 31 Progressive	1.2	1,316.0
1 Jump - 30 Progressive	1.2	1,354.9
10 Jump - 21 Progressive	1.2	1,705.3

*Multiples of the weighted averages of the respective offsetting restoration levels for a single representative invasive organism (Table 6), combined according to the dispersal scenarios.

As noted in US Geological Survey (2005), the HEA results in Tables 6 and 7 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 Red Lake River and the Lower and Upper Red Lakes to those estimated for the Red River and Lake Winnipeg in US Geological Survey (2005). The levels of offsetting restoration for the Red Lake River and the Lower and Upper Red Lakes in Table 7 are compared to the levels of offsetting restoration for the Red River and Lake Winnipeg determined by US Geological Survey (2005) in Tables 8 and 9. Table 8 indicates lower potential consequences for the Red Lake River than for the Red River. Similarly, Table 9 indicates up to

one order of magnitude lower potential consequences for the Lower and Upper Red Lakes than for Lake Winnipeg.

Table 8. Offsetting Restoration for 31 Biota of Concern: Comparison of the Red River and the Red Lake River.

	------Offsetting Restoration------	
	Red River*	**Red Lake River****
Dispersal Scenario	**(River-Miles)**	**(River-Miles)**
Slow Invasion		
0 Jump - 31 Progressive	0.6	0.0
1 Jump - 30 Progressive	0.6	0.0
10 Jump - 21 Progressive	0.6	0.0
Fast Invasion		
0 Jump - 31 Progressive	3.1	1.2
1 Jump - 30 Progressive	3.1	1.2
10 Jump - 21 Progressive	3.1	1.2

*From Table 2 in Section 5.3 of US Geological Survey (2005)

**From Table 7

Table 9. Offsetting Restoration for 31 Biota of Concern: Comparison of Lake Winnipeg and the Lower and Upper Red Lakes

	------Offsetting Restoration------	
	Lake Winnipeg*	**Lower and Upper Red Lakes****
Dispersal Scenario	**(Acres)**	**(Acres)**
Slow Invasion		
0 Jump - 31 Progressive	1.9	2.8
1 Jump - 30 Progressive	360.0	70.4
10 Jump - 21 Progressive	3,583.7	679.0
Fast Invasion		

0 Jump - 31 Progressive	19,322.3	1,316.0
1 Jump - 30 Progressive	20,165.1	1,354.9
10 Jump - 21 Progressive	27,750.3	1,705.3
**From Table 2 in Section 5.3 of US Geological Survey (2005) **From Table 7		

3.2 Conclusions: Economic Consequences and Red Lakes and Red Lake River

This supplemental analysis extends the consequence analysis of US Geological Survey (2005) to include the Red Lake River and the Lower and Upper Red Lakes. This analysis employs the same habitat equivalency analysis model, biota dispersal methods and invasion rates, assumptions about offsetting restoration, and discount rate as used in US Geological Survey (2005). The results indicate 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 US Geological Survey (2005), these HEA results assume the feasibility and availability of appropriate restoration measures.

While the validity of that assumption is not clear, these results are 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 in US Geological Survey (2005). 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. Given that comparison, the conclusion in US Geological Survey (2005) that the majority of the potential consequences from risks of biological invasion would likely occur in Lake Winnipeg continues to hold.

The results indicated by this supplemental analysis may overstate the actual potential consequences for the Red Lake River and the Lower and Upper Red Lakes for two reasons. First, the Lower and Upper Red Lakes are treated as a single habitat. That may yield an overestimate of potential consequences since the narrow channel connecting the two lakes may impede the spread of water-born invasive biota while no such impediment is modeled in the HEA. The second reason these results may overstate actual consequences is that the same probabilistic outcomes determined by US Geological Survey (2005) were used in this supplemental analysis. The use of those probabilistic outcomes may yield an overestimate of potential risk consequences since the westward flow of the Red Lake River into the Red River presents an opposing force to the movement of water-born invasive species. These two factors may strengthen the conclusions of this supplemental analysis that the consequences of risk for the Red Lake River and the Lower and Upper Red Lakes are less than the consequences of risk foe the Red River and Lake Winnipeg, respectively.

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