RECLAMATION

Managing Water in the West

Communication Strategies and Tools for Reclamation: reporting changes in physical systems and proposed measures for adaptive mitigation.

Research and Development Office
Science and Technology Program
Final Report ST-2019-1603

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Mission Statements

Protecting America's Great Outdoors and Powering Our Future

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

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Effective communication promotes collaboration and cooperation between the Bureau of Reclamation (Reclamation), partner agencies/organizations, stakeholders, and the general public. The ability to effectively communicate information to a broad audience and ensure that messages are meaningful is essential for Reclamation in achieving its mission. This three-year study was initiated with the research question *"Can we develop simplified strategies and tools to: 1) better explain historical and potential future change to physical systems and 2) communicate Reclamation's response for adaptation and water resources management?"*. The resulting report presents recommendations to address those challenges through enhanced communication plans and data visualization guidelines to develop information products. Providing a suite of well-designed information products based on the interests and needs of a target audience is key to effective communication of study results.

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Communication Strategies and Tools for Reclamation; reporting changes in physical systems and proposed measures for adaptive mitigation

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Executive Summary

Effective communication promotes collaboration and cooperation between the Bureau of Reclamation (Reclamation), partner agencies/organizations, stakeholders, and the general public. The ability to effectively communicate information to a broad audience and ensure that messages are meaningful is essential for Reclamation in achieving its mission.

This three-year study was initiated with the research question *"Can we develop simplified strategies and tools to: 1) better explain historical and potential future change to physical systems and 2) communicate Reclamation's response for adaptation and water resources management?"*. This report presents recommendations to address those challenges through enhanced communication plans and data visualization guidelines to develop information products.

While study plans are detailed description of how a study will be conducted, corresponding communication plans are incongruously generalized. Integrating the plans brings communication considerations to an equal level of detail and reinforces the link between study purpose and audience. Development of a suite of information products based on the interests and needs of a specific audience becomes a defined purpose.

Data graphics are important elements in science-based reports. Properly executed, they serve as data rich displays of complex information. Data visualization guidelines, based in principles of visual perception and cognition, are provided in this report. Design aims to maximize information density and enhance clarity and focus in data graphics. Data visualizations directly support the focused message in information products.

The recommendations in this report serve as a starting point to advance effective communication within Reclamation. This work can be advanced through working groups separately refining implementation of communication plans, establishing a cadre of design professionals, acquiring data visualization tools, and exploring web applications for interactive data visualizations.

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Introduction

Effective communication promotes collaboration and cooperation between the Bureau of Reclamation (Reclamation), partner agencies/organizations, stakeholders, and the general public. The ability to effectively communicate information to a broad audience and ensure that messages are meaningful is essential for Reclamation in achieving its mission.

Reclamation presents and communicates changes to physical systems (both natural and anthropogenic) in reports and memoranda that are often highly technical in addressing complex interactions and outcomes. These documents provide a very detailed and thorough description of a study's analyses and findings. While these factually dense documents are useful in sharing and validating the study within the science community, they can fall short of conveying information in a way that is relevant for non-scientists. The amount and complexity of information is not at issue. Rather, there is a need to consider audience in disseminating information and developing information products that most effectively convey that information.

Scientists within Reclamation recognize the difficulty of communicating complex and multi-faceted study results to decision makers and stakeholders. A previous Reclamation study investigated communication in terms of "plain English" and provided guidance for report composition (Larsen 2015). PLAIN (2011) provides similar guidelines for a wide range of federal documents. Continuing in this effort towards improving communication, a three-year study, *Communication Strategies for Reclamation Scientists*[1], was initiated to develop tools and strategies for effective communication. This study is addressing a two-part research question:

Can we develop simplified communication strategies and tools to:

1) better explain historical and potential future changes to physical systems and

2) communicate Reclamation's response for adaptation and water resources management?

The scoping effort for this study revealed a need to produce a wider variety of information products which mirror the diversity of target audiences. Challenges in fulfilling this need include:

- Identifying the information needs and interests of the target audience;
- Matching information product style and content to the target audience;
- Leveraging the talents of those with a strong understanding of how visual information can and should be presented; and
- Accessing and using tools to generate quality information products.

[1] For clarity, study title as presented in the proposal is used here. In actuality, various Reclamation staff other than 'scientists' are involved in the communication process and, as such, appropriately recognized in this final report.

'Communication strategies' are presented in the context of a communication plan to address the first two audience-centric challenges listed above. The remaining two challenges related to developing data visualizations are addressed with a more technical approach as 'tools' based in principles of human cognition and visual perception.

These principles are presented in the *Data Visualization* section and translated into Design Guidelines which are then applied in demonstrating examples of data visualization. Data graphic types and tools to produce data visualizations are also presented as a starting point for those in Reclamation whom have interest in taking an elevated approach to developing superior data information products.

Communication Strategies

Communication Plan Components

Existing Reclamation communication plan guidelines are designed for single issue initiatives (e.g., safety, core values, centennial observations, environmental management systems (EMS)). Though not intended as guidance in preparing communication plans required for studies conducted and reported by Reclamation, they are nevertheless used for lack of alternative guidance.

A typical communication plan establishes an organization's goals and methods for sharing information about programs and initiatives with shareholders and the public. Though each are tailored to a particular program or initiative, all are based on some combination of the same general components:

Statement of purpose	Explains why the communication plan is being developed and what it is meant to achieve—an overall goal.
Objectives	Specific steps to accomplishing the goal. Reclamation guidelines suggest they be S.M.A.R.T. (**S**pecific, **M**easurable, **A**ction-oriented, **R**ealistic, and **T**ime sensitive).
Situational Analysis	Includes analyses such as PEST (**P**olitical, **E**conomic, **S**ocial, and **T**echnical factors affecting an organization) and SWOT (an organization's **S**trengths, **W**eaknesses, **O**pportunities, and **T**hreats).
Audience	Identifies those with whom communication will be undertaken. Reclamation guidelines additionally suggest identifying how the audience receives information.

Messages	Translating objectives into relevant messages, often as key messages, umbrella statements, or talking points to incorporate into discussions and information products.
Tools and Activities	Methods and media that will be used to communicate, including public outreach. Reclamation separates this component into 1) **Strategies** (general path to take) and 2) **Tactics** (specific activities to implement the plan).
Work Plan	Identifies resources, budget, and timelines for implementing the communication plan.
Evaluation	Assess the effectiveness and success of the communication plan in meeting goals and objectives.

Applying such an outline to prepare a communication plan for a complex, multifaceted study results in general statements that do not provide adequate direction for developing information products; more specifically, the content of information products based on the specific stakeholder/audience information needs. There are two options for developing more effective communication strategies. One option is to extract a study plan's purpose, objectives, and tasks into a stand-alone communication plan and address each with specificity. This would result in separate, yet coordinated, documents for the study plan and communication plan. Another option is to incorporate communication components into the study plan, resulting in a single document that includes both the study plan and communication plan. Either way, the intent is to more fully integrate the study and communication process.

Decision makers initiate studies to gain information for use in meeting their management obligations and responsibilities and a wide range of scientists and specialists are involved in conducting and reporting the studies. By integrating the study and communication plans, the information needs of the decision makers are clearly articulated for each and every study plan component. This level of clarity helps the scientists and specialists determine how to most effectively provide the required data and information (e.g., tailoring analyses to provide specific types of information). In addition, audience considerations made for each aspect of the study can drive reporting strategies.

Communication Strategy #1:

Integrate Communication and Study Plan components

The Components for Primary Focus

This study focuses on further developing four of the communication plan components, including *Purpose, Objectives*, *Audience*, and *Tools and Activities*[2] to develop improved strategies for effective communication.

Purpose and Objectives is enhanced to the granularity of describing tasks; analyses that are to be conducted and reports to be made for the study. By articulating purpose with this level of detail, scientists can better design the analysis to meet identified data and information needs. Objectives are formulated to also include communication strategies for reporting study information and results.

The scoping phase of this study included a cursory review of the literature pertaining to *Audience* in communication strategy development. Reclamation does not apply audience assessment and segmentation to the degree described in many of papers reviewed. Though not pertinent to this effort in developing strategies and tools for communication, the literature review provides useful insight and potential areas for future study into audience involvement.

Communication plan *Tools and Activities* are addressed, per Reclamation guidelines, as *Strategies and Tactics*. *Reporting Methods and Outreach* will be used in this report as a more appropriate nomenclature to Activities. *Tools* are separated out and presented later in this report as software programs and technical approaches for data visualization. Activities and strategies are reserved for use as more general and broader terms.

Purpose and Objectives

The first questions addressed in preparing a *communication plan* are purpose and objectives; also referred to as "goals and objectives" in Reclamation guidelines. The intent of a well-defined communication plan statement of purpose, as described in Reclamation guidelines, is to inform, persuade, or motivate to action. In most cases, the purpose of Reclamation studies is to provide information about changes in physical systems, associated ramifications, and potential mitigation options.

Communication plans and study plans both include a definition of the overall study goal or purpose. However, in contrast to the "purpose" of a communication plan, study plan purpose focuses primarily on defining the scope of the study. Such a scope will often define the range of forcing conditions (or conditions that fall beyond our control in water management - hydrologic conditions are a good example) and range of water management alternatives (e.g. adaptation and mitigation options) (Reclamation, 2011, 2015b, 2016c). The study plan then describes categories of inquiry that will be pursued to accomplish the study's

Communication Strategy #2:

Describe purpose and objectives for analytical tasks in terms of conducting and reporting

[2] Reporting Methods and Outreach is used instead of Tools and Activities as a more straight forward and less confusing descriptor. Tools are presented in this report as technical approaches for data visualization.

purpose and presents them as objectives. Which again, parallels a communication plan's description of required steps for accomplishing the goal. Where communication plans and study plans begin to diverge is in the level of detail provided through the '*Tasks*' section of a study plan. This section includes descriptions of specific analyses that will be conducted in support of the study's objectives (modes of inquiry). It is here that there is opportunity to consider and articulate *Purpose* and *Objectives* in terms of communication strategy at a scale that addresses the data that is being generated and how it needs to be conveyed. Rather than describing *Purpose* and *Objectives* in general terms for the overall study, description should also be provided at levels of detail that includes specific data and end products. Broad statements of communication purpose and objectives may simply indicate that reports will be produced as a mean to disseminate information. At the level of '*Tasks*' more detail can be provided as to the purpose of communication and objective that would be fulfilled by a particular report. This in turn determines what the information products need to be.

Study plan tasks involving data acquisition, generation, and complex analysis invariably list a technical memo as a deliverable. The technical memo is essentially an information product to provide a record of an analysis that had been performed. It is intermediary to a final report. There is typically an additional task to compile/composite/consolidate all technical memos into a final report. Though not explicitly stated, it is generally understood that this information will inform stakeholders and be used in management decisions. As a public document, it is made available to the public.

With *Purpose* there is automatically *Audience*. They are inextricably linked (Patt and Dessai 2005 and Moser 2010). It follows that communication goals (what), audience groups (who), and presentation and delivery of information (how) are all necessarily interrelated. This is not reflected in the evolution of data information products described above.

The primary reason for producing a technical memo is to provide highly specialized information that contributes collectively to the overall purpose of the study. Technical memos may be posted on a study's web site in their entirety prior to completion of the final report. While transparency in study methodology and data generation is an implied purpose of posting the technical memos, the actual communication purpose is narrowly focused to the individuals preparing the final report. These documents often fall short of providing effective communication with stakeholders. Broader consideration of purpose and audience for interim communications such as these will allow for more effective communication, thus further enhancing transparency and facilitating communication throughout the study process.

Communication Strategy #3:

Provide information products designed for a broad audience to report progression of the study

Given this example of interim technical memorandums, a more audience-appropriate format and level of detail would be something similar to that of an abstract, with careful attention paid to using "plain language" (i.e., direct and acronym-free). Differing from a true abstract, data visualizations could be included to enhance the density of information being provided. Also, in condensing the technical memorandum, it is important to preserve an explanation of the process and the relationship between facts. Presenting complex information using clear and simple examples, figures, and mental models brings more informational clarity and understanding to a typical audience (Moser 2010).

A poll conducted by the National Science Board found that eight in ten Americans do not understand what it means to study something scientifically (NSB 2014). How well this characterizes the typical audience of a Reclamation study has not been evaluated. Nevertheless, this reveals that a potentially large portion of a target audience may have difficulty understanding reports that consist primarily of scientific findings and results. A preponderance of data and facts can lead to “not seeing the forest for the trees”. This is not to say that a particular audience cannot understand the facts or science presented, but that important concepts, dynamics, and the “big picture” may be getting over-shadowed.

Just as technical memos are compiled into a report, summaries derived from technical memos could likewise be compiled to form a condensed, more audience-friendly, version of the final report.

Audience and Evaluating Communication Effectiveness of Current Practices

Studies conducted by Reclamation are relevant for a variety of audiences that generally include decision-makers, stakeholders, concerned publics, and scientists. Analyses and results are communicated through the distribution of information products, primarily in the form of detailed reports. A review of existing Reclamation information products shows that there is room for improvement in meeting the informational needs of our typical audiences. This review considered an audience’s level of understanding of the phenomena being investigated, familiarity with the scientific approaches used in analyses, as well as sheer volume and complexity of facts and figures present in a typical report.

Important considerations in the development of information products that will be effective for specific audiences include:

- Information Overload[3]: restrict summaries to include only the most pertinent information;
- Clarity: use plain English and be concise in the explanation of complex concepts and dynamics;
- Visuals: leverage easily readable data visualizations to support analysis and emphasize key findings.

A literature review of “audience assessment” revealed a collection of reference material predominantly investigating communication strategies for addressing climate change issues (Andrews 2010, CRED 2014, Moser 2010, NRC 2010). Strategies centered around 1) changing or influencing behavior, perceptions, and beliefs and 2) motivating action or participation. The social sciences are employed for the purpose of segmenting audiences into various groups,

[3] This should not be confused with data density. This pertains to ancillary or supporting data and information that are otherwise incorporated into a finding and obviously represented in the finding.

allowing for tailored messaging for that specific group. One risk with this approach is the potential for different messages to arise; creating confusion in the least and becoming contradictory at the worst.

A study conducted by the George Mason University Center for Climate Change Communication and the Yale Project on Climate Change Communication identified six distinct groups: alarmed, concerned, cautious, disengaged, doubtful, and dismissive across a spectrum of highest to lowest belief in climate change (Maibach et al. 2009). Other studies identify local audiences on the basis of communities of place, interest, identity, and practice (Andrews 2010, CRED 2014, Kahan 2014). Reclamation generally recognizes audiences based on the latter model.

Another audience model from the corporate community is role- and power-based (NCSU 2016). This model is more pertinent as a framework within which communication strategies are determined internally and through the dynamics between multiple partners. When developing and promoting a communications strategy using this model, audience segmentation is based on influence or control over the strategies. These include:

- **initial audience –** can decide whether to forward the message/document to others. This may be the person who initially requested the document/message;
- **primary audience** - the target audience to reach to accomplish purpose and that decides whether to act on recommendations or respond to the purpose of the message;
- **key decision-makers** - those who have ultimate power over the communication objective;
- **secondary or hidden audience** - those who might see or hear about your message and whom the message will influence whether directly or indirectly (in business, includes attorneys);
- **gatekeepers** - individuals with the power to block the message.

This study does not investigate these audience models. Audience assessment and segmentation are used primarily when purpose is to influence change in behavior, perceptions, or beliefs. In many cases, these strategies are applied based solely on categorical characteristics of a population segment and an assumed response; pitfalls in over-reliance of models (Kahan 2014). Rather, this study suggests that a more practical and effective approach is simple recognition of the diversity within target audiences, the use of critical thinking in identifying audience needs and developing communication strategies, and direct interaction with the audience to refine strategies and evaluate communication effectiveness (Patt and Dessai 2005, Locker and Kaczmarek 2006, Moser and Dilling 2011, CRED 2014).

Communication Strategy #4:

Interact with the audience to assess information needs and effectiveness of communication strategies

While there are regulations that limit the collection of audience information (PL 96-511 1980), Reclamation Directives and Standards (Reclamation 2016d) provides that “requests for comment and collection of information from a person on a voluntary basis in public meetings, workshops, or similar public participation activities" is exempt from OMB clearance for surveys involving 10 or more people. This type of interaction could be useful for Reclamation when conducting studies. Future investigations may benefit from exploration of more interactive or participatory approaches to audience characterization (Beier et al 2016, Tally et al 2016).

Reporting Methods and Outreach

Reporting Methods

Reclamation makes most completed reports available in hard copy as well as digitally through the Bureau's internet website (http://www.usbr.gov). Links under the heading 'Featured Resources' provide access to environmental documents by region (Environmental Resources & Reports), including studies on climate change (Pacific Northwest Region). In addition to standard web pages, Reclamation has also published story map web applications (ESRI Story Maps) to distribute study information. Story map web applications combine narrative text with maps and other embedded content in an interactive framework. This form of presenting information is being more widely used. This type of application allows users to zoom into, and pan around, maps to explore their particular area of interest. The Pacific Northwest Region Public Affairs Office is developing guidelines for developing story maps and submitting them for approval to be published.

This study offers no recommendations for improving reporting methods in terms of distribution of information products. The emphasis is rather content and quality. Notable Reclamation information sites include:

- **SECURE Water Act Report Data Visualization:** The SECURE Water Act web page has links to a variety of information products that includes the full report to Congress fact sheets for each basin, and the SECURE Report Data Visualization (an ESRI story map web application) (https://www.usbr.gov/climate/secure/).
- **WaterSMART:** The WaterSMART webpage, separate from the SECURE web page, has links to a series of webpages including general information about the program, Basin Studies, WWCRA, and Landscape Conservation Cooperatives (LCCs). Links lead to increasingly detailed information. (https://www.usbr.gov/watersmart/).
- **Climate Change Orientation Presentations:** The climate change orientation presentations were developed as a seminar for Reclamation staff. Though developed for technical specialists and "mission audiences," much of this material could be reused in presentations prepared specifically for other audience segments. (http://www.usbr.gov/climate/orientation/index.html).
- **Colorado River Basin Study:** The Colorado River Basin Water Supply and Demand Study website provides a record of the study and examples of presentations for public outreach. (http://www.usbr.gov/lc/region/programs/crbstudy.html).

Outreach

Though outreach is a component of a complete communication plan, it is usually prepared separately from the communication plan and presented as an appendix of the study plan. The result is three separate, yet interdependent documents: Study Plan, Communication Plan, Outreach Plan.

Communication Strategy #5:

Integrate Outreach and Study Plan components

An investigation of outreach methods and techniques is beyond the scope of this study. Nevertheless, it is worth mention that it is integral to a communication plan in disseminating information and acquiring audience input. The Missouri Headwaters Basin Study, Plan of Study (Reclamation 2016c) is a good example of a Study Plan that provides clear purpose and objectives for outreach broken into tasks and subtasks with sufficient consideration for audience.

Data Visualization

Graphically displaying numerical data in the form of charts, graphs, and plots is an efficient means to communicate complex information. Remarkable in how much information data graphics provide, these data-rich visual displays are able to convey complexity in a way that humans are capable of comprehending (Tufte 1990, Medina 2008). Though the visual display itself can bring clarity to the data (Tufte 2001), translation from data to information ultimately succeeds through observance and application of design principles based on visual perception and human cognition (Few 2004a, Tufte 2001). Additionally, effectiveness of the visual graphic relies on using a display type that is appropriate to the data type and analysis (Tufte 1997, Few 2004b, Chartoff and Schwabish (n.d.)). The following sections discuss visual perception and cognition and present a catalog of data graph types. A larger discussion then provides design guidelines in considering visual concepts and display.

Visual Perception and Cognition

Visual analysis is functionally divided between the preattentive stage of perception and a later cognitive stage of forming separate features into objects (Thornton and Gilden 2007, Martinovic et al 2008). Preattentive processing is a parallel process with the eye and brain working in concert to interpret simple features within milliseconds. The basic building blocks in this visualization process are termed *preattentive visual attributes* that draw the viewer’s immediate attention (Ware 2012). Figure 1 provides example preattentive attributes that include form, color, and spatial position and demonstrates how they differentiate information in data visualization.

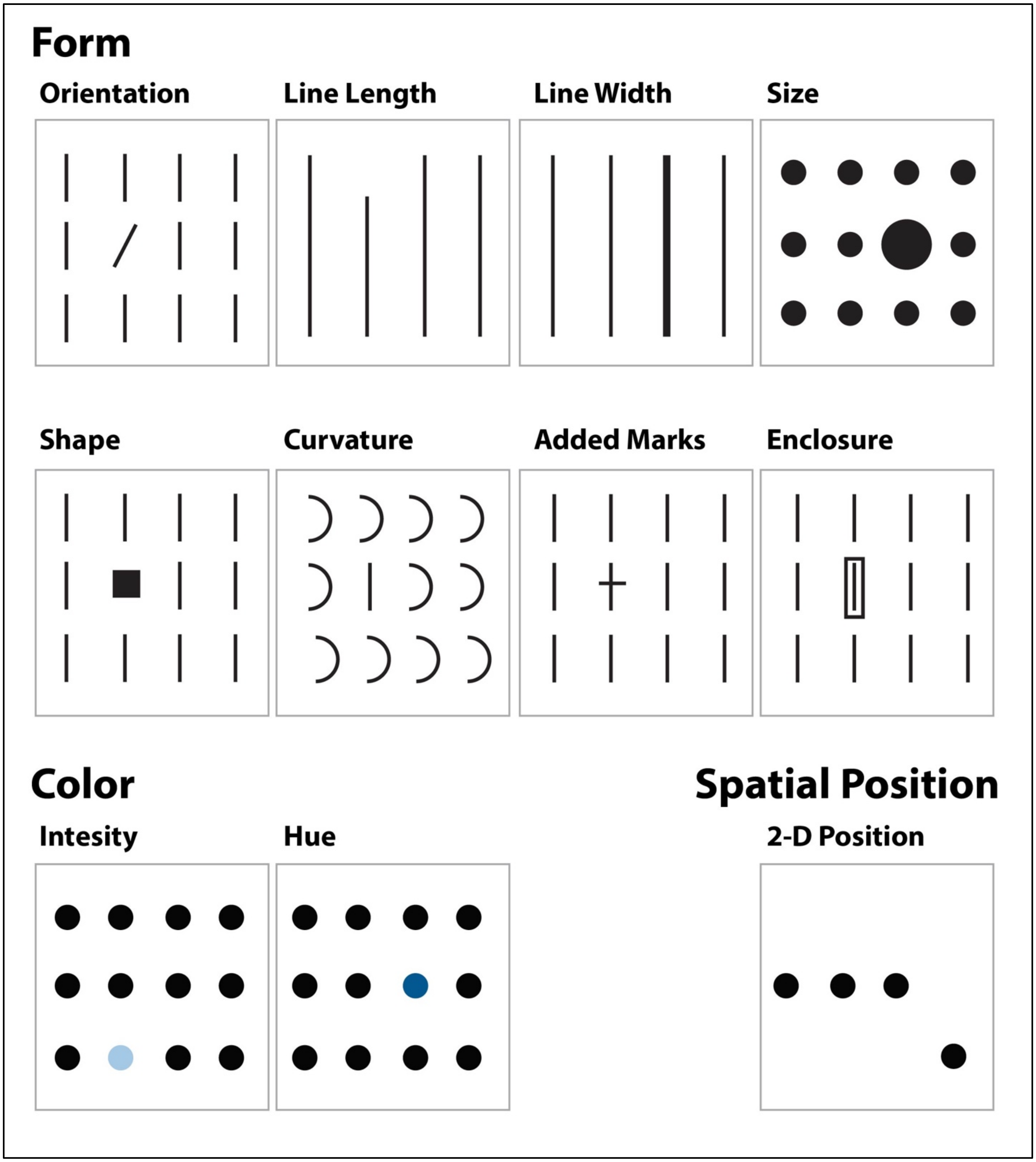


Figure 1. Preattentive Attributes Image credit: Colin Ware, Information Visualization: Perception for Design

Following the passive preattentive stage, the cognitive stage is a series of rapid active processes that divide the visual field into region and patterns (Ware 2012). This process in the brain is likened to random access memory (RAM) in a computer; readily accessible with high-speed processing capabilities, though at limited memory capacity (Few 2004a). Some contend that working memory holds only five to nine objects (or chunks) at a time (i.e., Miller's Law), with an increase in capacity being possible when meaningful patterns are detected and the information is organized into groups; referred to as being "chunked". A more mechanistic analogy is how squirrels "chunk" their nuts, grouping similar types together to help in later locating the caches based on pattern.

A classic example of the difference between *preattentive* and *attentive* cognitive processing is to count the number of occurrences of an object within a figure. The first example involves using *serial attentive processing* to count how many times that the number eight occurs in the array of numbers.

720806279437897972729057295023790327907979729089207390790
246766079707907577973720620874238070027202787028047380073
702072105203700920802308270972075306042924042682749820974
657209794302467660797737079075779707370207210520370098979
720572954238070027202787006208742300272027870280473800737

In the next example, using the same array of numbers, the number eight was encoded with a *preattentive attribute* (a color of darker hue in this case).

720806279437897972729057295023790327907979729089207390790
246766079707907577973720620874238070027202787028047380073
702072105203700920802308270972075306042924042682749820974
657209794302467660797737079075779707370207210520370098979
720572954238070027202787006208742300272027870280473800737

This binary example demonstrates how all the "eights" in the array are quickly recognized and do not require the cognitive effort of an active (attentive) search. Counting the number of occurrences is made easier.

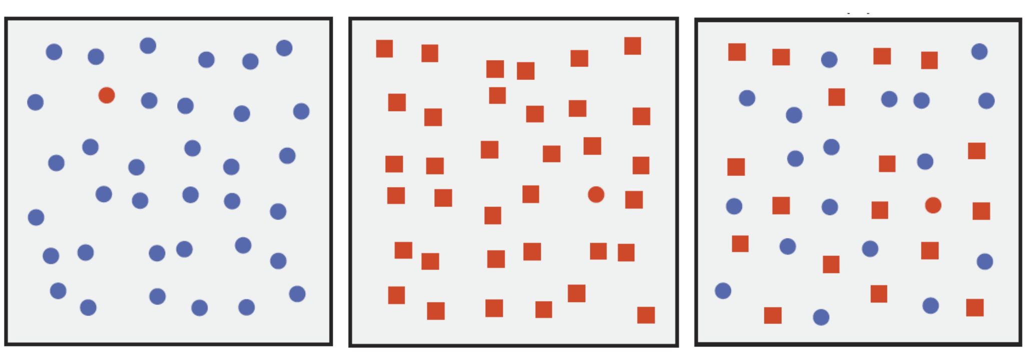
Another example of directing attention is demonstrated by the highlighted single "one" within the milieu of numbers.

720806279437897972729057295023790327907979729089207390790
246766079707907577973720620874238070027202787028047380073
702072**1**05203700920802308270972075306042924042682749820974
657209794302467660797737079075779707370207200520370098979
720572954238070027202787006208742300272027870280473800737

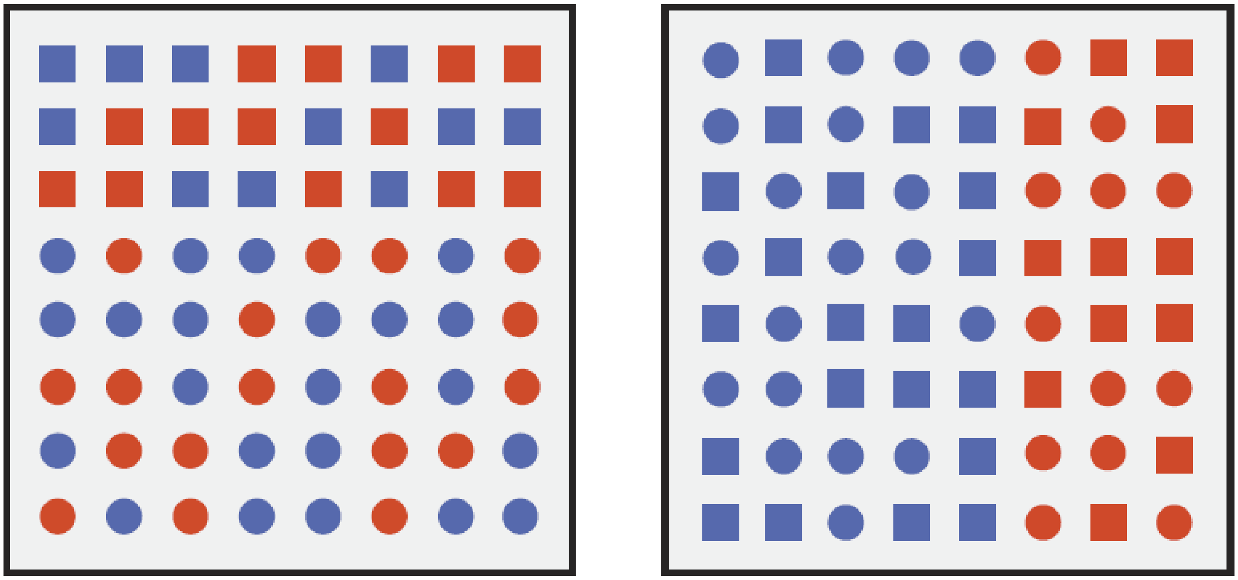
Multiple target recognition involves more complex application of pre-attentive attributes, taxing the capacity of pre-attentive "chunking" as well as the latter stage of visual cognition of active search and association. Preattentive attributes can assist in pre-processing the pattern, such as differentiation of odd and even numbers. Consider the inquiry as to whether the numbers in the array is skewed in the proportion of odd and even numbers represented. This inquiry demands a more attentive search as the number of distractors increases. Distractors can be graphic elements as well as the attributes of the elements(s). While the color of the numbers does help make the distinction between odd and even in the example below, the shape and location of the individual numbers also emerges as a factor in recognition, detracting from visual properties of hue and requiring more attentive cognition to address the inquiry.

720806279437897972729057295023790327907979729089207390790
246766079707907577973720620874238070027202787028047380073
702072105203700920802308270972075306042924042682749820974
657209794302467660797737079075779707370207200520370098979
720572954238070027202787006208742300272027870280473800737

Using the preattentive visual features hue and shape as targets, the following examples also demonstrate how targets cannot be detected preattentively with joint presence of two or more visual properties (Healy and Enns 2012). In the first tile, immediate attention is brought the red circle based on differences in hue. In the second tile, shape is the differentiating factor in preattentively detecting the red circle from features of the same hue. When the properties of shape and hue are used in combination, the target red circle is not found without a difficult search.



Another interesting characteristic of *preattentive attributes* is feature hierarchy (Healy and Enns 2012). When features of varied hue are grouped by shape, a preattentively recognized pattern does not emerge quite as quickly as when the same features are grouped by hue. It appears color can effectively direct attention in a visual graphic whereas other preattentive attributes such as *form* and *spatial position* provide analytical patterns to perceive relationships and variation (Few 2016).



Data Graph Types

The various types of visual graphics, such as bar charts, line graphs, and scatter plots have been categorized in several classification systems based on function (Camoes 2013, Schwabish and Ribecca 2014, Abel 2016, Ribecca (n.d.)). Functions include comparing values, representing distribution, displaying trends over time, and illustrating correlations or relationships between variables. These classifications serve as a resource to understand the anatomy and facility of data graphic types when selecting which to use in visualizing data. The following diagram (Figure 2) displays a modified classification of data graph types (and associated function) commonly used in Reclamation reports. Several data graph types are introduced that have potential for use.

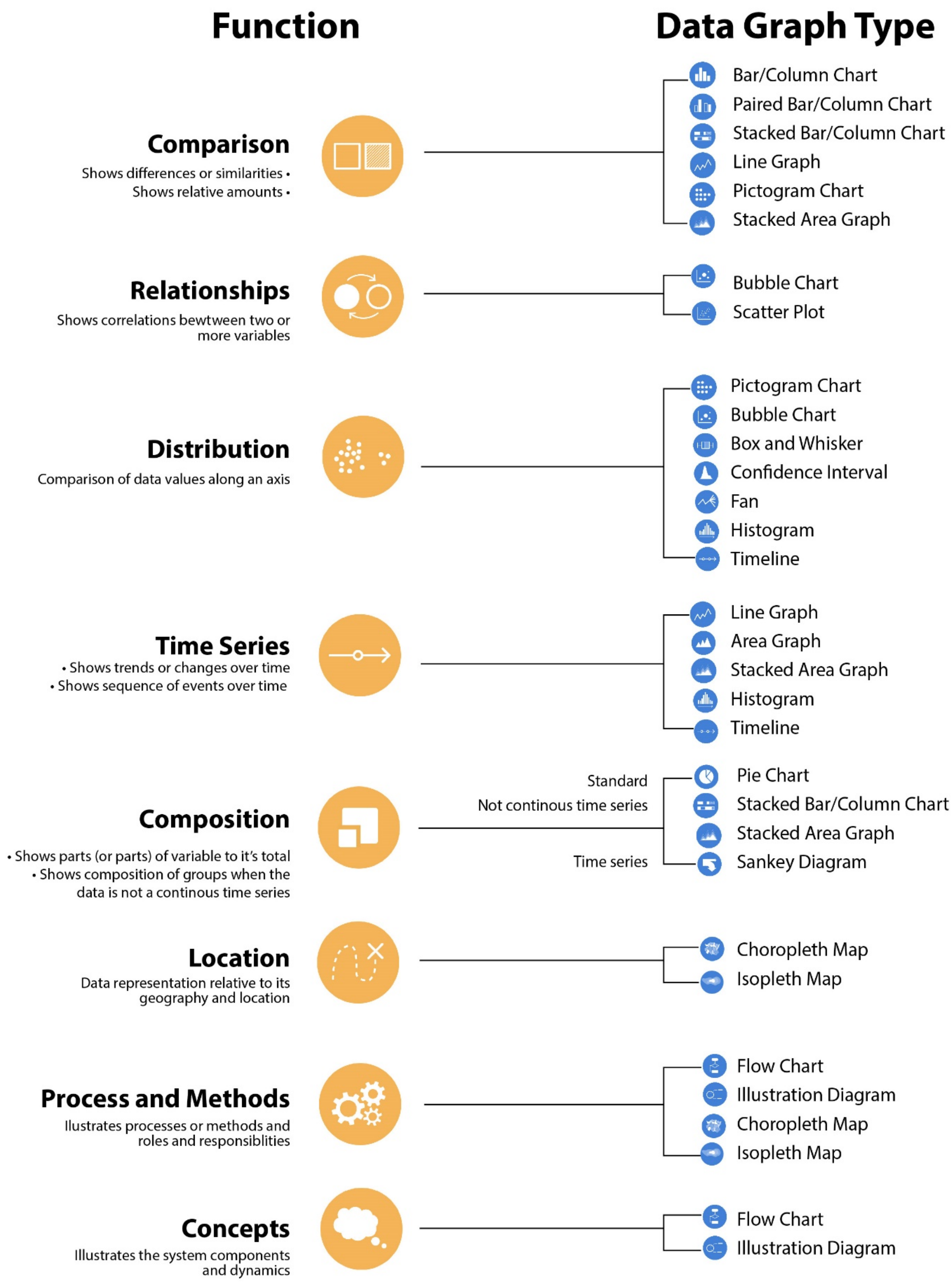


Figure 2. Form/Function Classification Scheme for Data Visualization

Data visualizations have also been grouped by nature (conceptual versus data-driven) and purpose, (declarative versus exploratory) as displayed in Figure 3 (Berinato 2016). Conceptual visualizations include flow charts and white-board brain storming diagrams that are differentiated as declarative or exploratory, respectively. Data-driven visualizations includes data graph types used in the analytical process. Data driven graphics can also differentiated between those that are declarative (e.g., explanatory in reporting findings) and those that are exploratory (e.g., exploring data in the initial stages of an analysis).

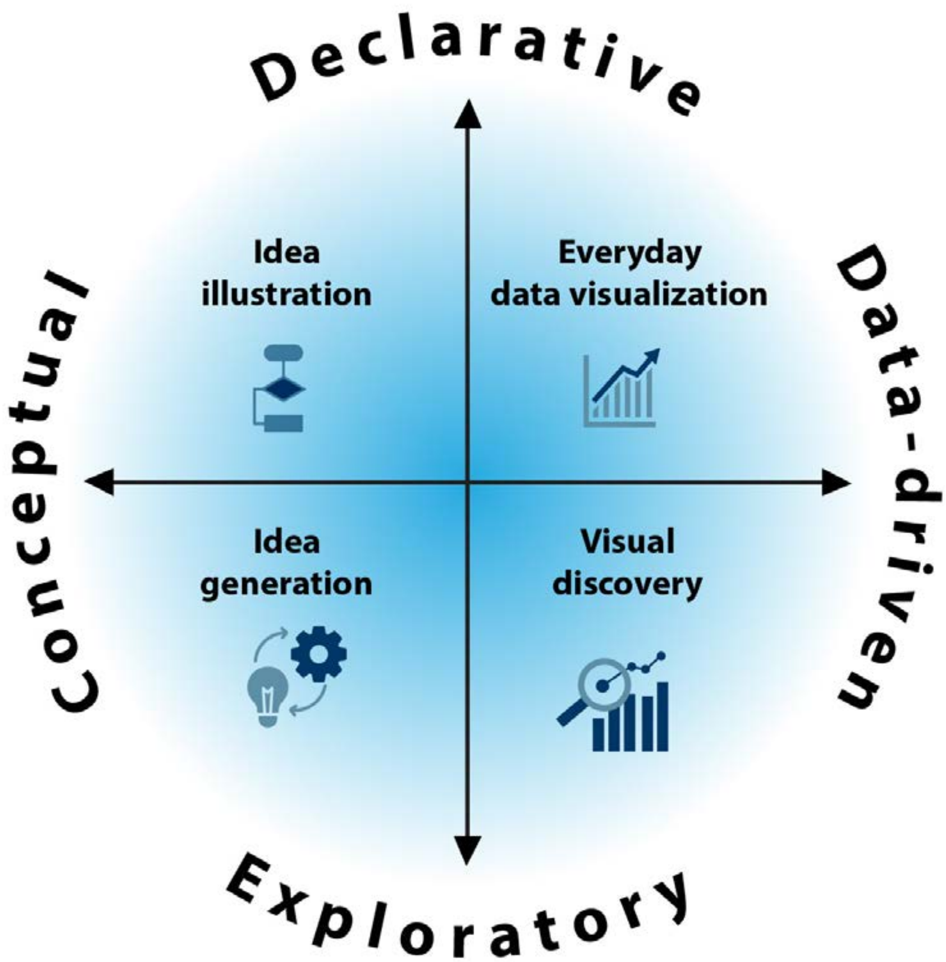


Figure 3. Nature/Purpose Classification Scheme for Data Visualization

Scientists construct exploratory data graphics with minimal formatting to merely inspect the raw data for patterns in the form of differences or similarities, trends or distribution, and outliers or anomalies. Data processing is performed, and additional exploratory graphs are constructed to facilitate further analysis and to translate those patterns into findings. Explanatory data visualizations are constructed post-analysis to describe those findings. Vestiges of exploratory formatting are sometimes carried over to explanatory graphics and redesign may be required, which could include using a different data graph type. The following section provides practical examples of redesign.

In relating the two data graph classifications to each other (i.e., form/function classification scheme to nature/purpose classification scheme), the conceptual hemisphere (idea illustration and generation) in Figure 3 relates to the methods/process and concept functions listed in Figure 2. The nature/purpose data driven hemisphere relates to all the other remaining functions of the form/function classifications.

Design Guidelines

Introduction

This study focused primarily on works by Edward R. Tufte and Cole Nussbaumer Knaflic as the primary sources of information for design principles and guidelines. Tufte's books (*Envisioning Information*, *Visual Explanations: images and quantities, evidence and narrative*, *The Visual Display of Quantitative Information*, and *Beautiful Evidence*) are referenced throughout this report. Cole Nussbaumer Knaflic's blog *Storytelling with Data* is a valuable resource for design principles and is the source of many of the examples and tools presented here. Design principles and guidelines developed for cartographic application by Eduard Imhof are equally important and referenced here. We consolidate these resources as a solid starting point in establishing fundamentals of graphic design.

Graphical excellence communicates complex ideas with clarity, precision, and efficiency in providing the viewer "the greatest number of ideas with the least ink in the smallest space".

~ Tufte

Tufte (1990) makes special note of the complex cognitive abilities of humans and promotes high-density designs as the appropriate complement to human capabilities.

> "We thrive in information-thick worlds because of marvelous and everyday capacities to select, edit, single out, structure, highlight, group, pair, merge, harmonize, synthesize, focus, organize, condense, reduce, boil down, choose, categorize, catalog, classify, list, abstract, scan, look into, idealize, isolate, discriminate, distinguish, screen, pigeonhole, pick over, sort, integrate, blend, inspect, filter, lump, skip, smooth, chunk, average, approximate, cluster, aggregate, outline, summarize, itemize, review, dip into, flip through, browse, glance into, leaf through, skim, refine, enumerate, glean, synopsize, winnow the wheat from the chaff, and separate the sheep from the goats. And a lot of data are processed: recent evidence indicates that the optic nerve connecting the eye's retina to brain operates at 10Mb per second, equivalent to an Ethernet."

Despite these many abilities, there remain cognitive limitations that must be considered in the development of effective visual information. Human memory limitations in visual perception become increasingly apparent as the cognitive load of search and association grows more demanding (Few 2004a, Thornton and Gilden 2007, Martinovic et al 2008). This is relative to the amount of data that is being represented, how it is presented, and the composition of the data graphic. It pertains to the amount of effort required to contrast and compare results presented within singular data graphics as well as across pages of multiple-graphic displays (Tufte 2001, Nussbaumer Knaflic 15 June 2018 and 26 June 2018). The high data-density design guidelines presented here aim to mitigate high cognitive demand by enhancing multi-dimensionality within the data graphic through wise use of preattentive attributes and careful composition of data graphic elements. In more simple terms, when presenting highly complex information, careful attention should be paid to reducing "clutter". Effective "decluttering" of a graphic does not involve an arbitrary reduction of content. The principles, guidelines, and techniques presented in this report aim to address clutter in a way that does not diminish (but instead enhances) informational content.

Confusion and clutter are failures of design, not attributes of information.

~ Tufte

Dimensionality and Hierarchy

The first dimension of a data graphic is the immediate "what". The "what" refers to the main idea or purpose of the data graphic is all about and what immediate focus should be drawn too. After that, active visual search and exploration come into play; patterns and associations are being sought out to gain understanding. The successive dimensions might be in the context of "when", "where", "how". Yet another dimension is the number of variables presented in data graphs to draw comparisons and associations.

The most basic visual stratification techniques to order dimensions includes ***layering*** and ***separation*** (Tufte 1990). *Layering* creates a hierarchy of visual effects in emphasizing the more important elements of a data graphic and diminishing or eliminating the lesser important elements. This is accomplished with preattentive attributes (form and color) in ways that match and order information content within a data graphic (Figure 4). *Separating* clarifies the multidimensionality of the data through two-dimensional indexing of multiple images, typically sequentially (Figure 5). The following are very basic examples of these concepts:

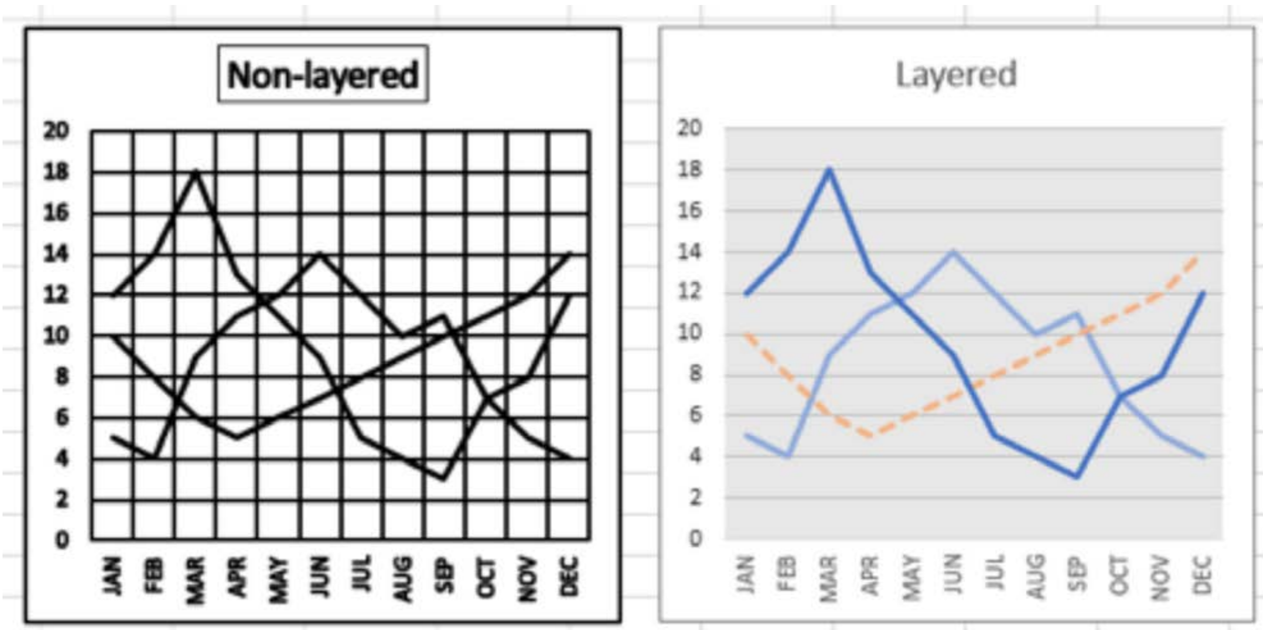


Figure 4. Example of Visual Stratification using Layering Technique

The non-layered data graphic above also exhibits how visual noise, optic effects, and negative space are generated in what is referred to as 1 + 1 = 3 effects (Tufte 1990).

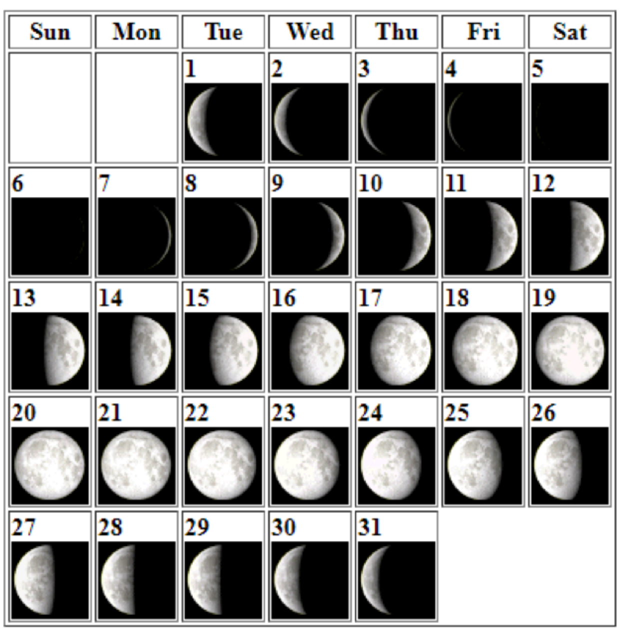


Figure 5. Example of Visual Stratification using Separation Technique

The primary purpose of the data graphic is to assist understanding by providing content that supports what you want to explain to your audience (SWD May 13, 2015, Tufte 2006). In practice, layering is often part of an iterative process in designing an effective visualization. Layering uses:

1) <u>preattentive attributes</u> (color, form, and spatial distribution) to visually stratify the data graph, and

2) <u>composition</u> by deciding what content to keep or discard and the ultimate placement of the data graph components.

"Before and after" examples of the iterative of effective visualization design/redesign are provided in Figure 6. These examples were extracted from the blog "Declutter this graph" (SWD 2017). Visit the blog to see all the steps and reasoning that lead from one to the other.

Figure 6. "Before and After" Example of Data Graphic Redesign

The redesign process is demonstrated in various "story telling with data" blogs and articulated in the principle of "data ink" to "non-data ink" ratio (Tufte 2006). "Data ink" is the core of the data graphic. "Non-data ink" can include the grid and x- and y-axes, along with the tic-marks and labels. The share of data ink relative to non-data ink should be maximized (within reason) with the deciding factor being the importance or significance of the information the ink provides. Another element of the redesign example provided above is the elimination of "chartjunk", overuse of graphic decoration or ornamentation and addition of a fake perspective to the data such as 3D effects. (Tufte 1990, 2001, 2006).

Design/Redesign Guidelines

Before presenting data visualization examples specific to Reclamation, we provide the following guidelines to consider in redesigning data visualization. We say *redesign* because you are most likely to receive a prepared data visualization rather than the raw data set. These guidelines will help realize the principles we discussed above.

Preattentive Attributes in Redesign

Color

Color is used in several ways to emphasize or highlight, differentiate, render quantity or transition, and impart visual appeal. Empirical rules expressed in the field of cartography for map design are also appropriate for data visualization (Imnof 2007). Those relevant to data graph redesign include:

> **A master reveals himself through the way he manipulates the different principles, using moderation on one hand, but applying deliberate and carefully considered emphasis on the other.**
>
> **~ Imhof**

- Avoid over-use of bright or very strong colors that have loud, unbearable effects and can appear disordered and confusing. Heavy rich colors should be limited to maxima and extrema or otherwise small areas to create expressive patterns.
- Avoid placing bright colors against white, especially over large areas. Bright colors against white can create unpleasant effects.
- Use muted, grayish, or neutral colors for large-area backgrounds or base colors to allow small bright areas to stand out most vividly.
- Use a uniform, basic color-mood in the composition.
- Use steady gradation in color to represent continuity in data (i.e., a steady, gradual change in values).

As summarized by Imhof, “In all questions of form and color composition, one should strive for simple, clear, bold and well-articulated expression. The important or extraordinary should be emphasized, the general and unimportant should be introduced lightly. Uninterrupted, noisy clamor impresses no one. Activity set against a background of subdued calm strength produces a deeply expressive melody.” Imhof’s perspective on maps and cartography is directly applicable to the design of data graphics and data visualization:

> “The map is a graphic creation. Even when it is so highly conditioned by scientific purpose, it cannot escape graphic laws. In other fields, art and science may take different pathways. In the realm of cartography, however, they go hand in hand. A map will only be evaluated as good in the scientific and didactic sense when it sets forth simply and clearly what its maker wishes to express. A clear map is beautiful as a rule, an unclear map is ugly. Clarity and beauty are closely related concepts.”

Form

Preattentive attributes of form are used in the same way as color; i.e., emphasize or highlight, differentiate, render quantity or transition. Visual hierarchy is realized through variance in size and line weight. Large and thick are synonymous with bold and bright in color; use with the same discretion as you would with color.

Spatial distribution

Inherent to the data when plotted in two-dimensional space, can be emphasized using other preattentive attributes.

Composition in Redesign

Prioritizing data graph components

What matters in data visualization is proper relationship among information layers being in relevant proportion and harmony (Tufte 1990). The redesign of data graph composition considers proportion and harmony of the data representation relative to the other data graphic components; x and y axes along with tic-marks and labels, grid lines extending from and associated with the axes. For example, think of a gridded background (such as in a table or line chart) and applying techniques to mute and calm the background so as not to compete with the data and allow the data to come forward. Composition redesign could also involve replacement of components, such as axis labels. If only a few certain values are important, an entire range of values does not need to be metered along an axis. The values can instead be placed directly at the pertinent data feature (bar, column, line, point).

While there are many best-practices and techniques for composition design, the over-arching guideline is **Maximize "data ink" - Minimize "non-data ink"**. How this is applied will be unique to the dimensionality of the information that is being presented in a data graphic.

<u>Integration of text, numbers, and images into the data graph</u>

It may seem counterintuitive to suggest adding objects to a data graph when decluttering is a priority, however adding detail to a data graph can clarify as well reduce search and memory load caused by the need to absorb information across several separate pages (SWD 2018, Tufte 1990). Considering our goal of producing data-dense graphics and pursuing "*graphical excellence*" a data graphic should stand on its own without additional explanation or research for information (Schwabish 2014).

Examples of Data Visualizations and Tools

We presented data graph examples organized by type and function in the preceding section of this report. That format is useful in searching for the appropriate data graph type that will most effectively present data and information as intended. Rather than following type or function schema in presenting the redesign discussion, we follow a generalized outline typical of Reclamation studies investigating changes in physical systems. Some data graph types relate more closely to one specific section of the report than another; most can cut across all sections. We choose to present examples in the order they would be presented in a study report to emphasize the evolution and flow of information in that form of a communication product.

Reclamation initiates studies when water supply/demand is likely to be affected by apparent or anticipated changes in physical systems. Factors influencing water supply include variation in precipitation and temperature which can affect runoff, streamflow, and storage (groundwater and reservoir). Though precipitation is the primary driver for supply, other drivers include the indirect effects of temperature on reservoir storage through evaporation rate and modified snow-melt runoff. Increased demand for water resources is driven primarily by population growth and development. The indirect effects of temperature impact net irrigation requirement due to changes in evapotranspiration rates further increasing demand. The following represents what might be a generalized outline used in studies that report these dynamics.

Introduction

Describes:
purpose and need for the study (what, where, why)
conduct of the study analyses that will be performed (how)

Includes:
maps of study area and study components (what and where)
flowcharts of roles and responsibilities and analytical processes (how)
conceptual diagrams system processes and dynamics

Supply and Demand

Describes:
observed supply and demand (existing conditions)
climate variation, and other factors, influencing future water supply and demand
impact of influencing factors on supply and demand (potential future conditions)

Includes:
numerous types of charts, maps, plots, and tables

Strategies for Adaptation and Evaluation of Proposed Actions

Describes:
alternatives for actions to mitigate effects and impacts
trade-offs between alternatives

Includes:
charts and tables

Introductory Information in a Typical Report

The Introduction section of a report explains **why** the study is being undertaken (i.e., the 'what for' or purpose and need), **where** it is being conducted (i.e., location and geospatial extent), and **how** it will be conducted. The 'how' may include descriptions of technical approach, an outline of administrative responsibilities, and chronology or sequence of workflow.

The data visualizations used in the introduction section are typically data graph types ***Flow Chart*** and ***Illustration Diagram*** for the function of conveying ***Process and Methods*** and ***Concepts*** and ***Maps*** for showing ***Location***. Flowcharts, diagrams, and maps have rather specific application:

Flowcharts – process steps, either analytical or administrative

Illustration Diagrams – graphic depiction of physical system models and concepts

Maps – geography and location of study area and components

Flowcharts

Design guidelines to consider in developing flowcharts are *Dimensionality and Hierarchy* in terms of 1) the actual organizational hierarchy and 2) layering within each text box. Another guideline, specific to flowcharts, not previously introduced, involves the recognition of data chart components as nouns and verbs (Tufte 2006). The names of groups and organizations (nouns) organized on the page are linked with lines (verbs) that represent some sort of interaction. Arrows at the end of lines can indicate causal mechanisms being made, such as direction, influence, or course of action. Color, line weight and style, and direct labeling also contribute in giving definition to the verb. The absence of visual clues renders roles and interactions ambiguous.

The following flow charts (Figure 7 through 13) illustrate organizational aspects or process steps of a study. They provide a range of examples of differentiating nouns and verbs with attributes. Over-applying attributes with elaboration such as 3D-effects and picture graphics, introduces what some might consider as “chartjunk”; superfluous elements in the data visualization (as in Figure 10 through 13). For comparison, Figure 14 provides a simplified version of Figure 13.

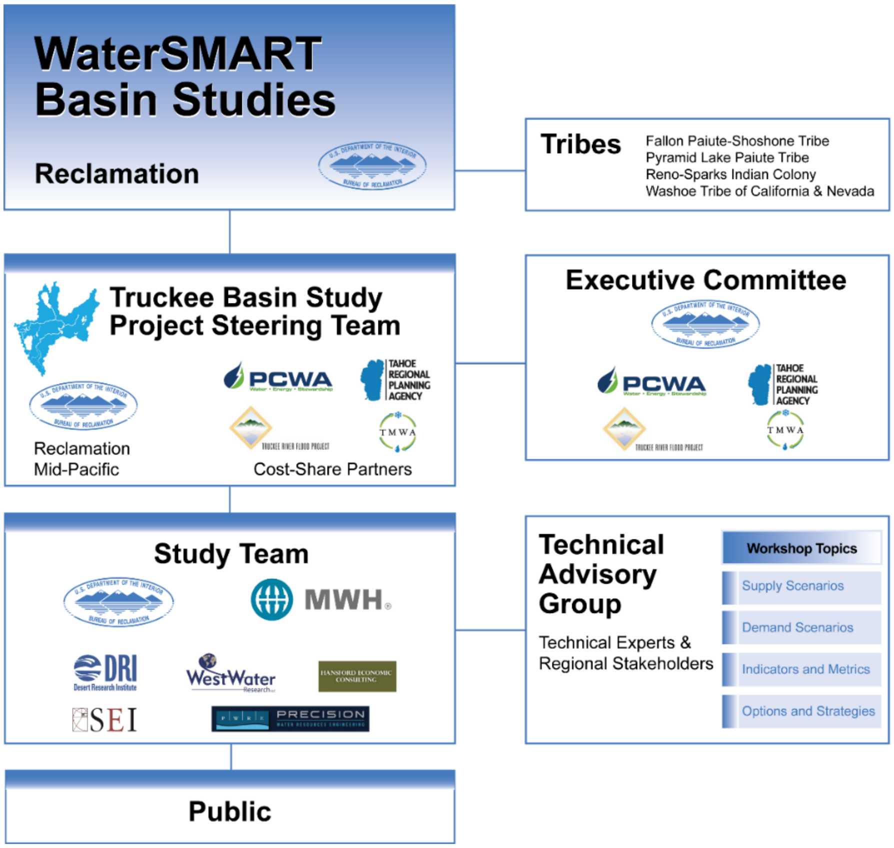


Figure 7. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 1-2. Organizational Structure for the Truckee Basin Study*

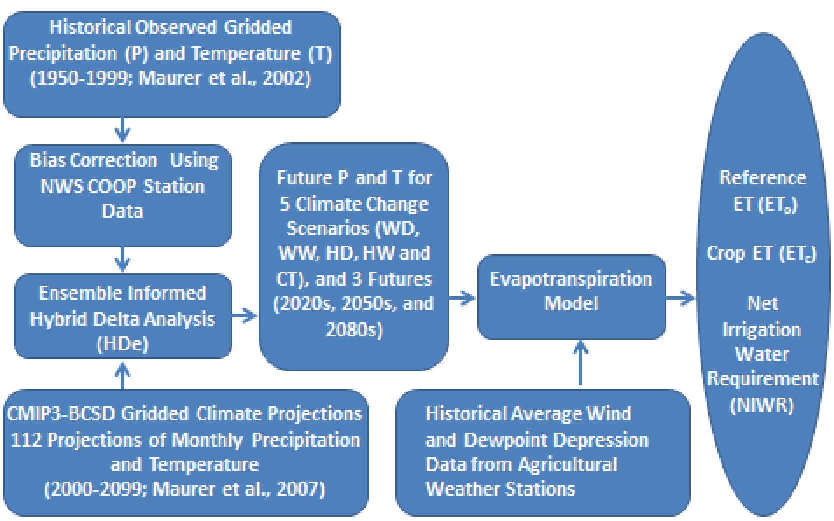


Figure 8. Example sourced from: WWCRA: Irrigation Demand and Reservoir Evaporation Rates (Reclamation 2015a), *Figure 1. Flow chart illustrating the general process used for estimating future irrigation demands.*

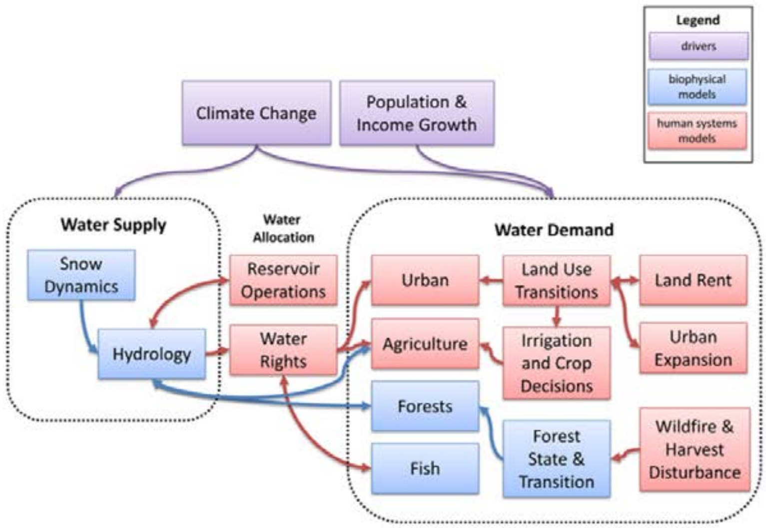


Figure 9. Example sourced from: https://inr.oregonstate.edu/ww2100/model-overview/model-introduction, ***Figure 2. Conceptual diagram of the Willamette water system showing how human and natural system modeling components link together within Willamette Envision (diagram by M. Wright).***

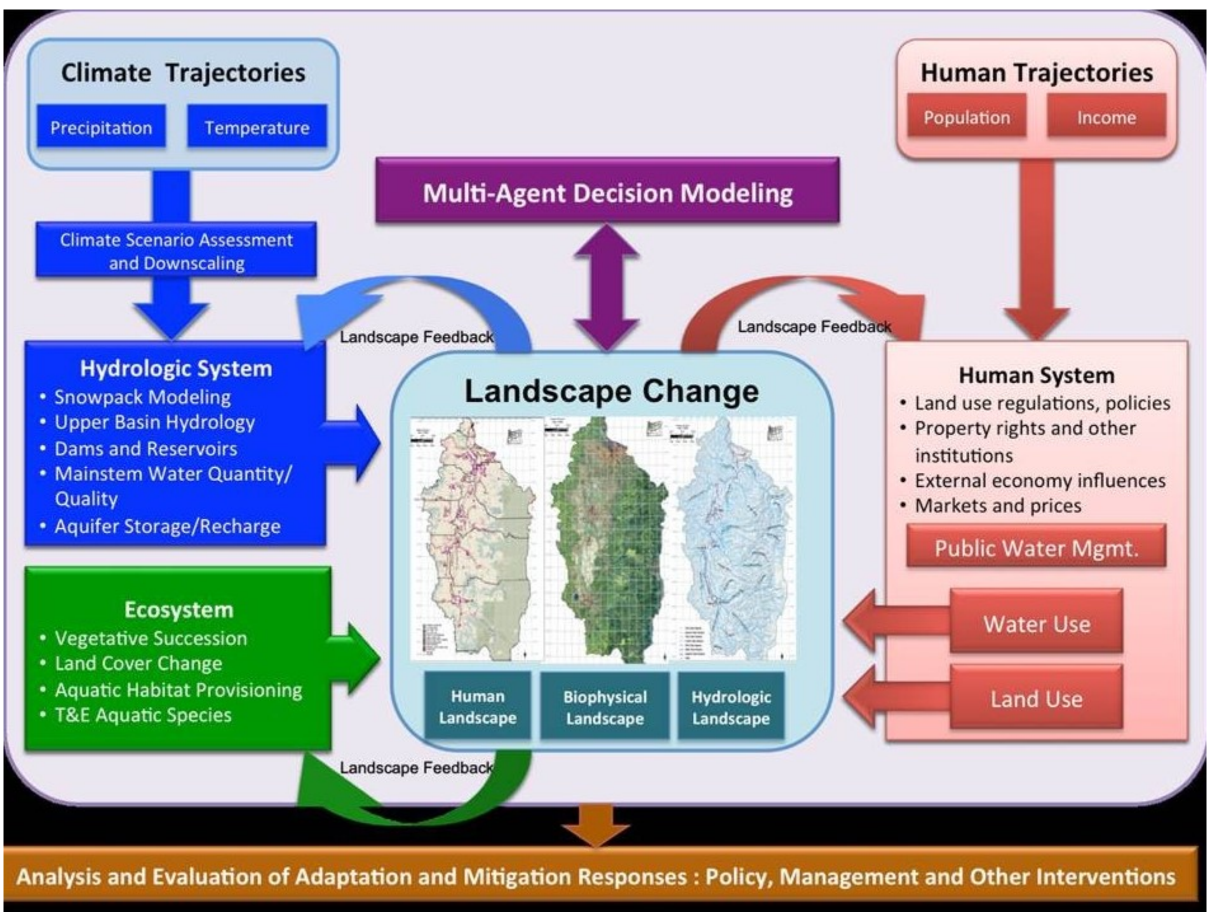


Figure 10. Example sourced from: http://ise.uoregon.edu/WW2100%20FactSheet_June2011.pdf, The Envision Framework.

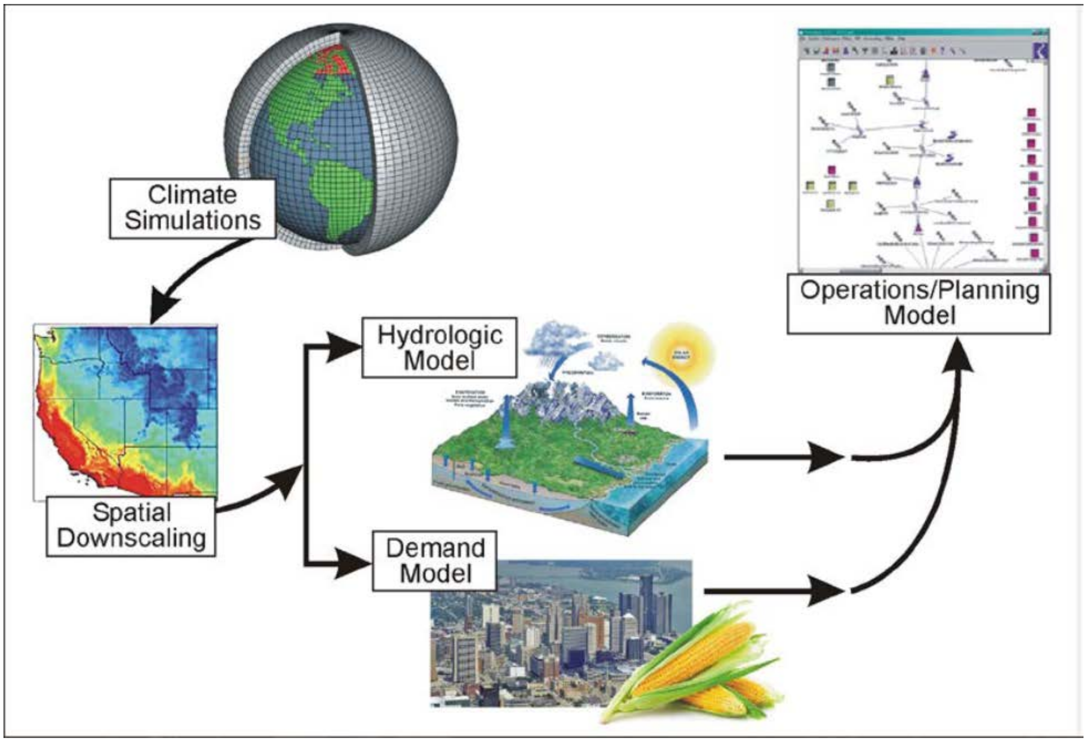


Figure 11. Example sourced from: WWCRA: Upper Rio Grande Impact Assessment (Reclamation 2013b), ***Figure 8. Modeling and analytical steps involved in the development of local hydrologic projections.***

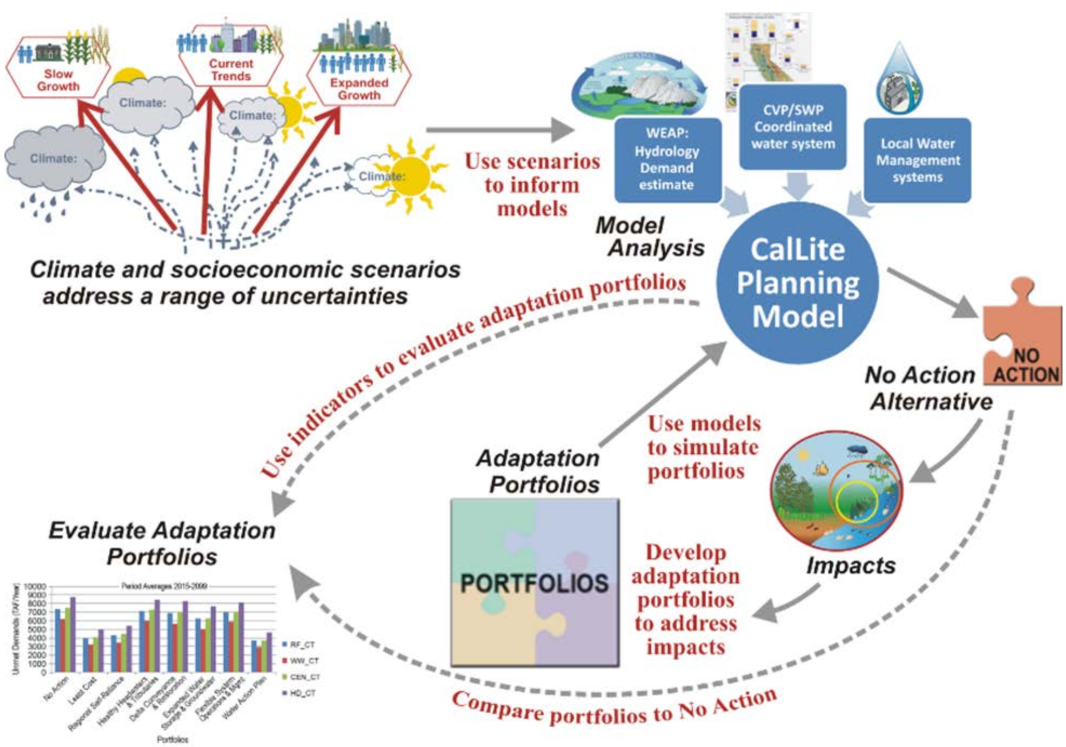


Figure 12. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), Figure 1-1. Technical approach and analysis process.

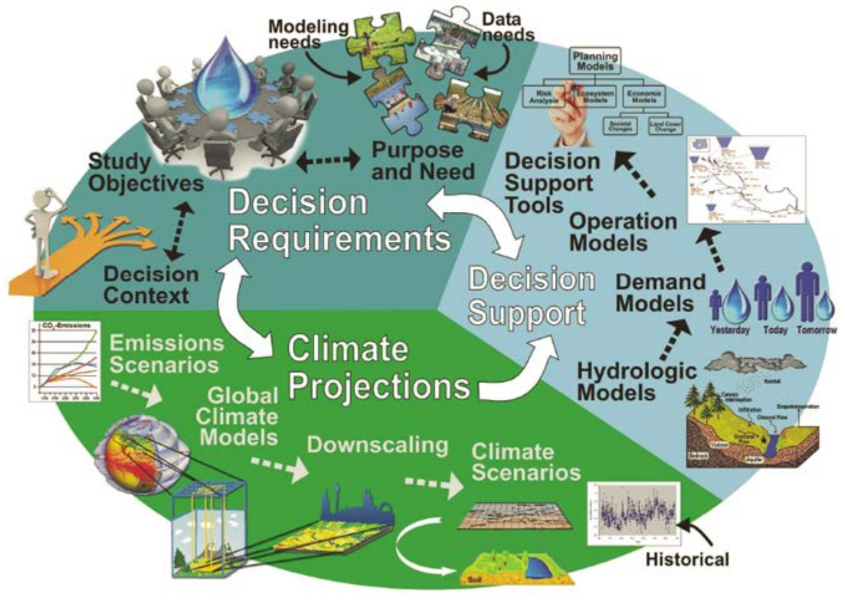


Figure 13. Example sourced from: WWCRA: Considerations for Selecting Climate Projections for Water Resources, Planning, and Environmental Analysis (Reclamation 2016a), ***Figure 14 Schematic overview of steps required to develop projections of future climate and to incorporate climate projection information into modeling and analysis in support of water resources and environmental planning, management, and decision making***

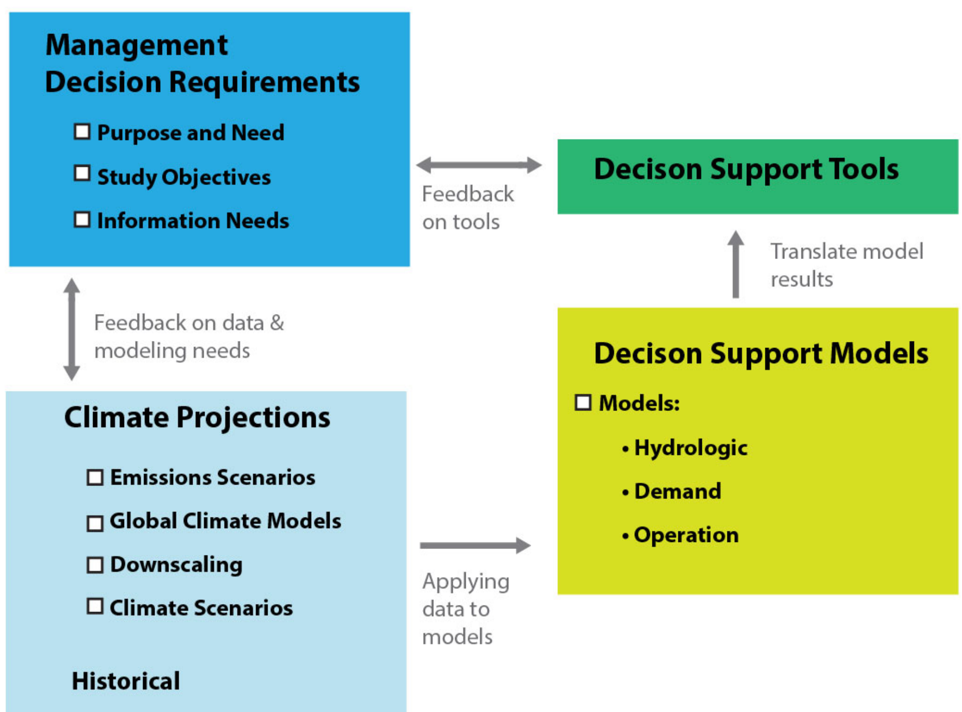


Figure 14. Simplified interpretation of figure 13.

Illustration Diagrams

Natural systems are complex processes that involve numerous input/outputs, cycles, and interactions. It is often easier to portray complex systems in illustration than to write a description of all the components and inner-workings. The following series of illustration diagrams provides examples varying in range of complexity (Figures 15 through 19). Many of conceptual diagrams come from other sources while others may be composed in-house. In using complex and highly illustrative diagrams, the application and scale at which it will be reproduced (e.g., document or poster).

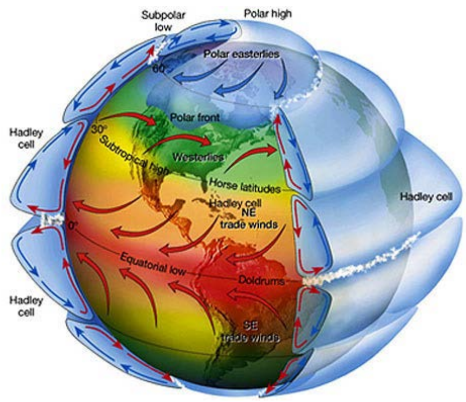


Figure 15. Example sourced from: WWCRA: Upper Rio Grande Impact Assessment (Reclamation 2013b), Figure 12. Atmospheric circulation in the climate system (Hadley cells) (source: National Aeronautics and Space Administration (NASA), nd).

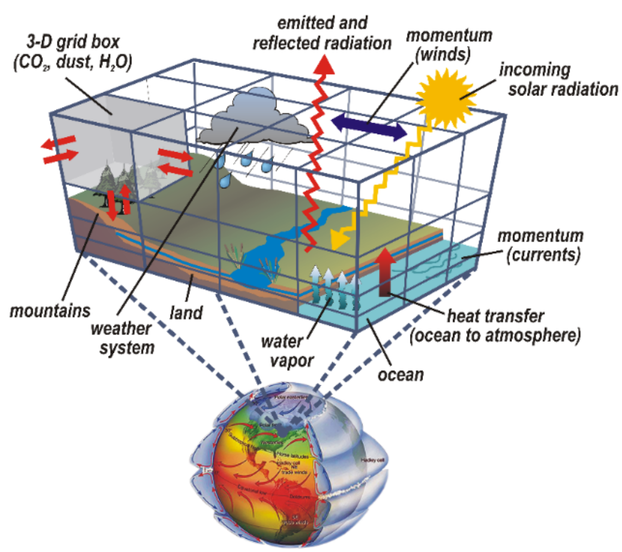


Figure 16. Example sourced from: WWCRA: Considerations for Selecting Climate Projections for Water Resources, Planning, and Environmental Analysis (Reclamation 2016a), *Figure 26. Schematic illustration of a global climate model (GCM).*

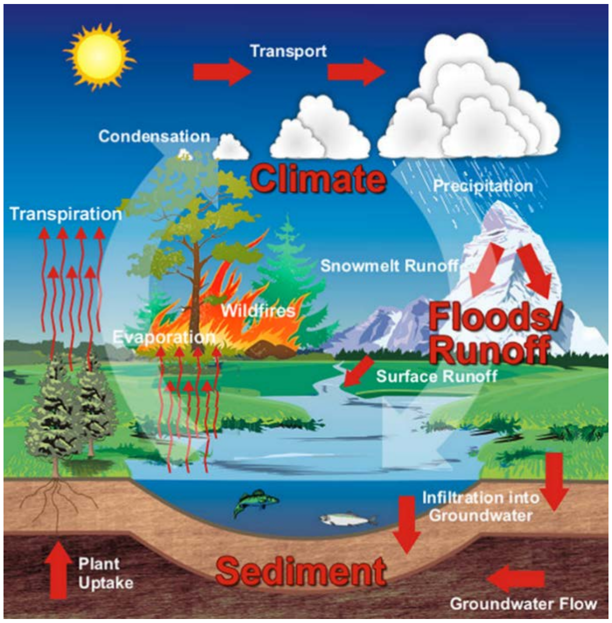


Figure 17. Example sourced from: Knowledge Stream: Climate Variability and Extremes (Reclamation 2016b), *Figure 23. Potential impacts from climate change on sediment processes.*

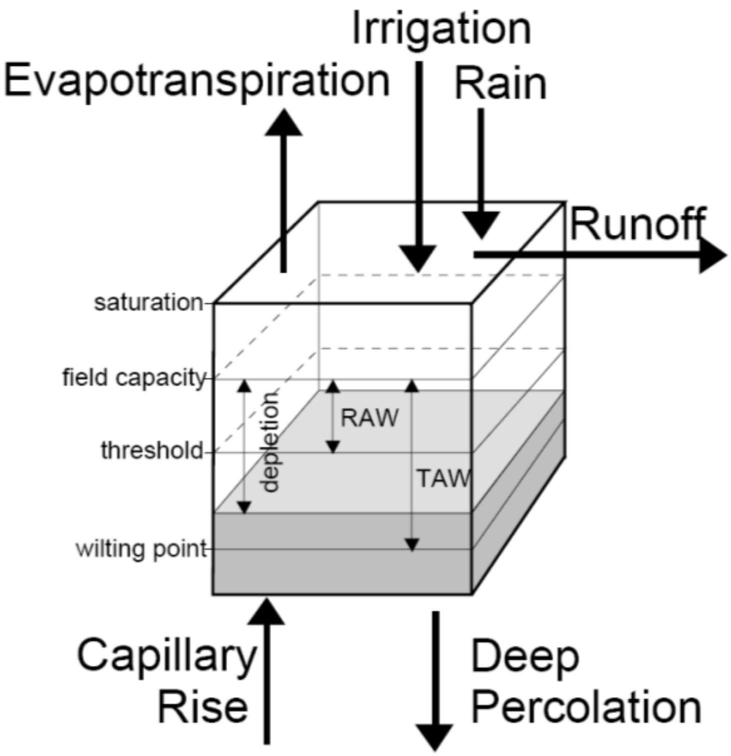


Figure 18. Example sourced from: WWCRA: Irrigation Demand and Reservoir Evaporation Rates (Reclamation 2015a), Figure 6. Schematic of the FAO-56 solid and root zone water balance adopted in the ET demands Model. Capillary rise in this study was assumed to be negligible. Modified from Allen et al. (1998).

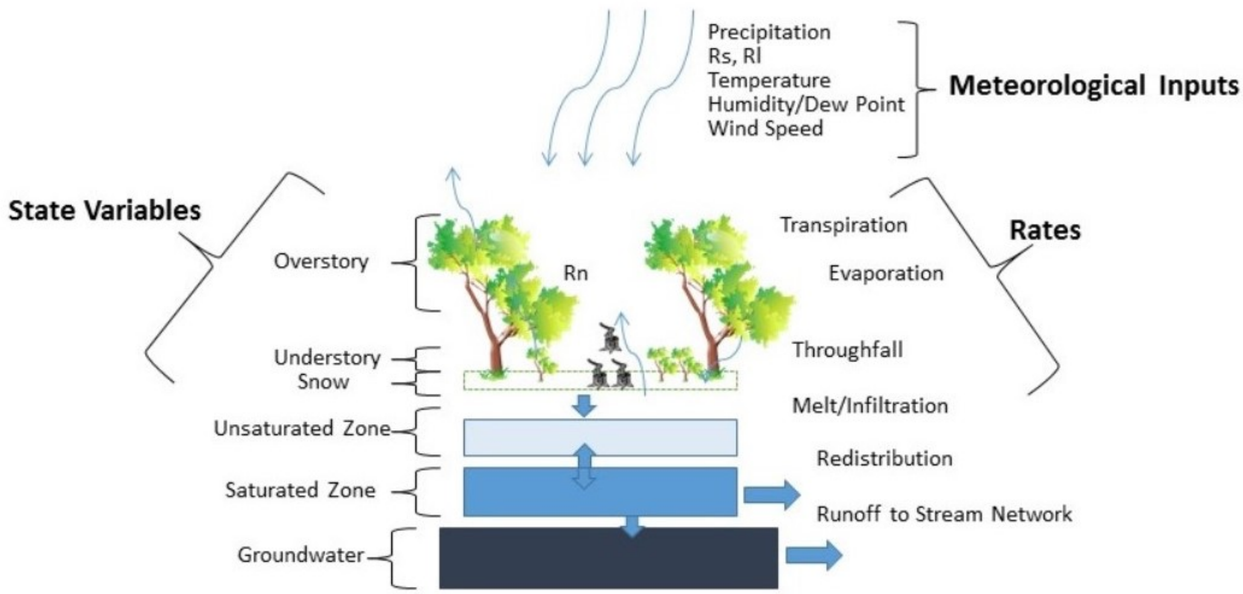


Figure 19. Example sourced from: http://inr.oregonstate.edu/ww2100/analysis-topic/hydrology, ***Figure 1. Hydrologic modeling within Willamette Envision involves movement of water through a set of conceptual reservoirs simulating soil and groundwater (diagram by K.Vacher).***

Maps

A map is a form of data representation that is used when geographic location or spatial relationship is important. Design guidelines recommended by Imhoff are relevant and preattentive attributes are key to good cartography. The following are examples of that.

Figure 20 emphasizes geography in displaying the location of area designations whereas Figure 21 is a more simplified rendition of relative location and spatial relationships. In one case, sensory attributes are largely used to depict terrain (topographic hillshade) and hydrography (blue water); symbols and aspects of the visualization that are intuitive (Ware 2012). These attributes are pseudo-realistic and follow standard convention. A depiction of landscape is not always needed presenting geospatial data in a map. In the other case, location and spatial relationships are emphasized by de-emphasizing natural elements (i.e., depiction of topography, land cover, or other landscape features). Landmarks are included for geographic reference.

In both map examples, line weight and application of bright colors are used as preattentive attributes to differentiate or highlight important features. These attributes are entirely arbitrary and must be ‘learned’; requiring definition in the legend to allow interpretation. The combined use of preattentive attributes (form and color) and organizing the information into groups facilitates interpretation.

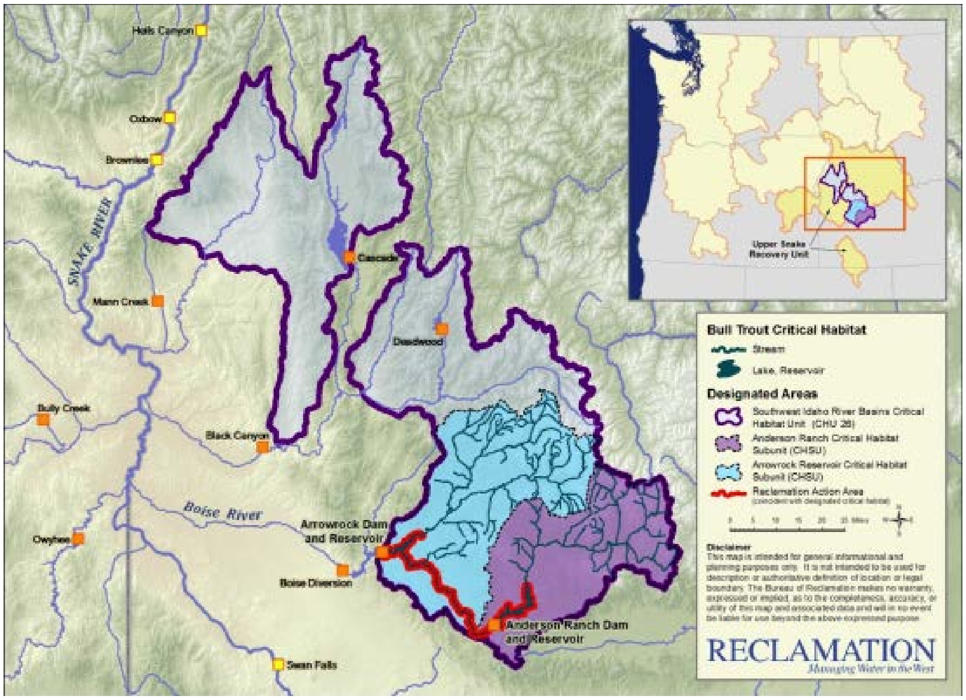


Figure 20. Example sourced from: Biological Assessment for Bull Trout Critical Habitat in the Upper Snake River Basin (Reclamation 2013a), *Figure 2. Southwest Idaho River Basin Critical Habitat Unit 26 boundary.*

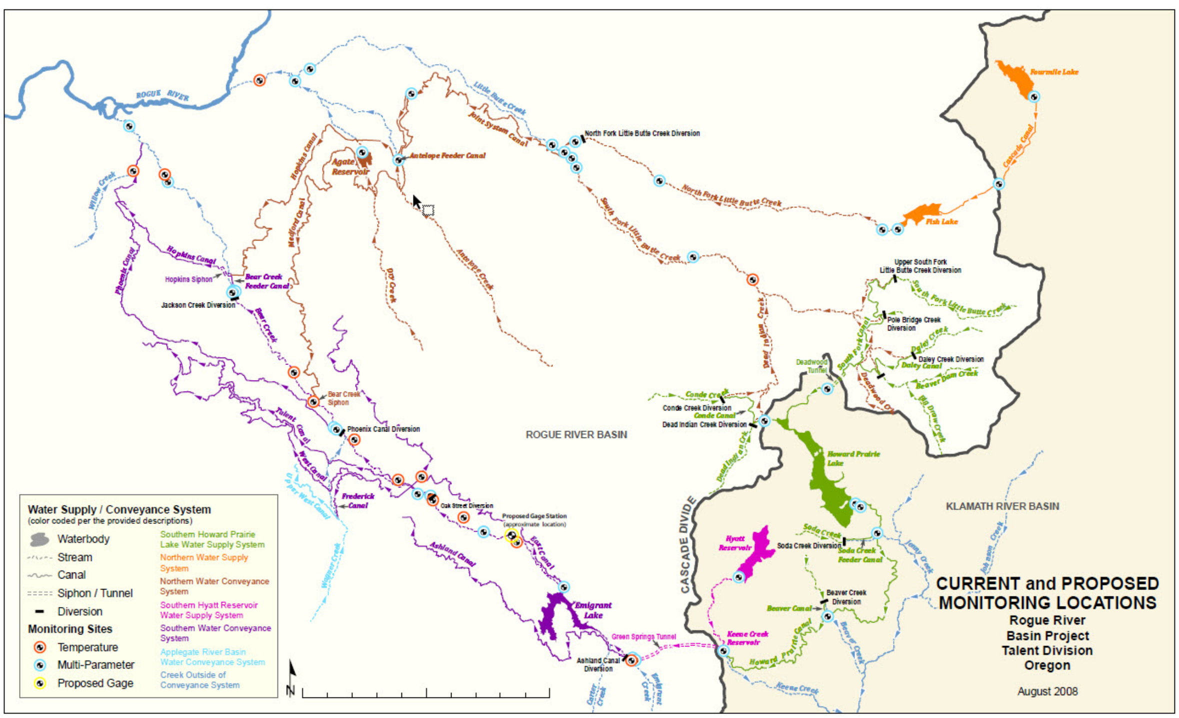


Figure 21. Example sourced from: Biological Assessment on the Future Operation and Maintenance of the Rogue River Basin Project (2009), *Figure 3-7. Rogue River Basin's Project current and proposed monitoring locations.*

Water Supply and Demand

Water supply and demand analyses are at the core of many Reclamation studies. The analyses are initiated with descriptions of existing conditions based on data from recent observations or historical data from past decades. Projections of potential variations in climate describe how conditions may change. Demand analyses establish baseline data including current uses and shortages. Projected or anticipated changes in demand are based on a myriad of factors which include growth (population, industry, and agriculture), crop evapotranspiration rate, and natural resources. Further analyses are performed to determine how the change in physical systems might affect supply and demand.

Data visualizations used for representing these analyses represent all the functions listed in Figure 2. The data graph types that are typically used include: ***Bar/Column Chart (single, paired, and stacked)***, ***Line Graph***, ***Scatter Plot***, ***Confidence Interval***, ***Fan***, ***Pie Chart***, and ***Choropleth / Isopleth Maps***. A series of these examples are presented here following the approximate order they may be presented in a study report.

Having been extracted from published reports and separated from narrative text, this series of data visualizations shows the importance of integrating explanatory and interpretive text in the data graph when presented as a stand-alone source of information (Schwabish 2014, SWD 2018, Tufte 1990). Additionally, though these example data graphs serve the purpose of presenting sequential steps in the analyses conducted over the course of the study, they may be limited to just that. They serve the purpose of presenting the study in a technical report. Other information products can be produced based on the scientific analyses and findings of study reports by reframing data graphs within a narrative that describes purpose and need of the study, physical system dynamics, and outcomes and ramifications. Data graphs in such information products would be redesigned and tailored as data visualizations focused on system processes rather analysis processes.

Precipitation - Observed

Time-series data, such as precipitation and temperature, are most frequently visualized with the line graph. The area graph, stacked area graph, and histogram are other data graph types that can be used in visualizing time-series data (Figure2). Design considerations to be made with these data graph types is to reduce non-data ink and insert descriptive text.

The following line graph (Figure 22) and histogram (Figures 23 and 24) time-series examples present total annual precipitation and average monthly precipitation. In viewing these examples, the first question that may come to mind is “what do these patterns mean and what is the significance in the amounts and trend?”. Descriptive text could be used to point out point such aspects in the data. The data presented in the isopleth map (Figure 25) is multi-temporal data reduced to a single 30-year average, as opposed to monthly or annual averages, and presents a spatial rather than a temporal pattern. It offers another representation the physical system under study.

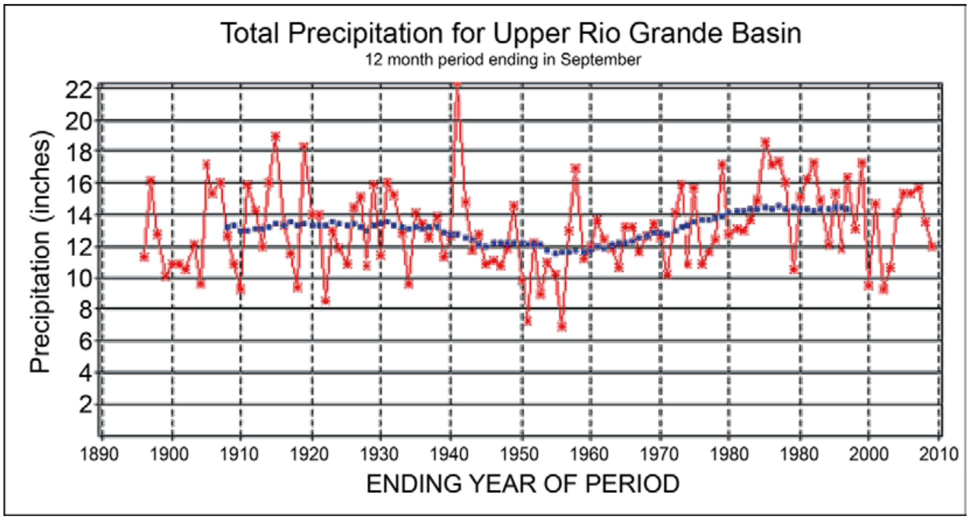


Figure 22. Example sourced from: WWCRA: Upper Rio-Grande Impact Assessment (Reclamation 2013b), Figure 11. Observed annual precipitation, average over the Upper Rio Grande Basin. Red line indicates annual time series for the given geographic region. Blue line indicates 25-year moving annual mean.

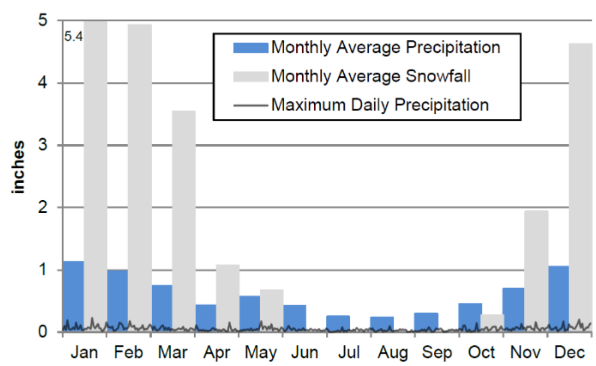


Figure 23. Example sourced from: Truckee Basin Study: Basin Study Report (Reclamation 2015d), ***Figure 3-15. Monthly Average Precipitation at Reno-Tahoe International Airport (1938-2012)***

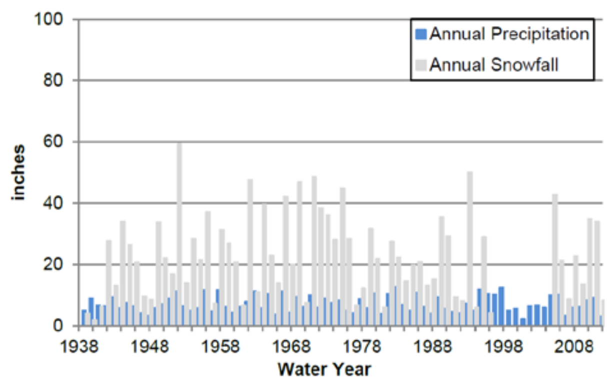


Figure 24. Example sourced from: Truckee Basin Study: Basin Study Report (Reclamation 2015d), ***Figure 3-16. Annual Precipitation at Reno-Tahoe International Airport (1938-2012)***

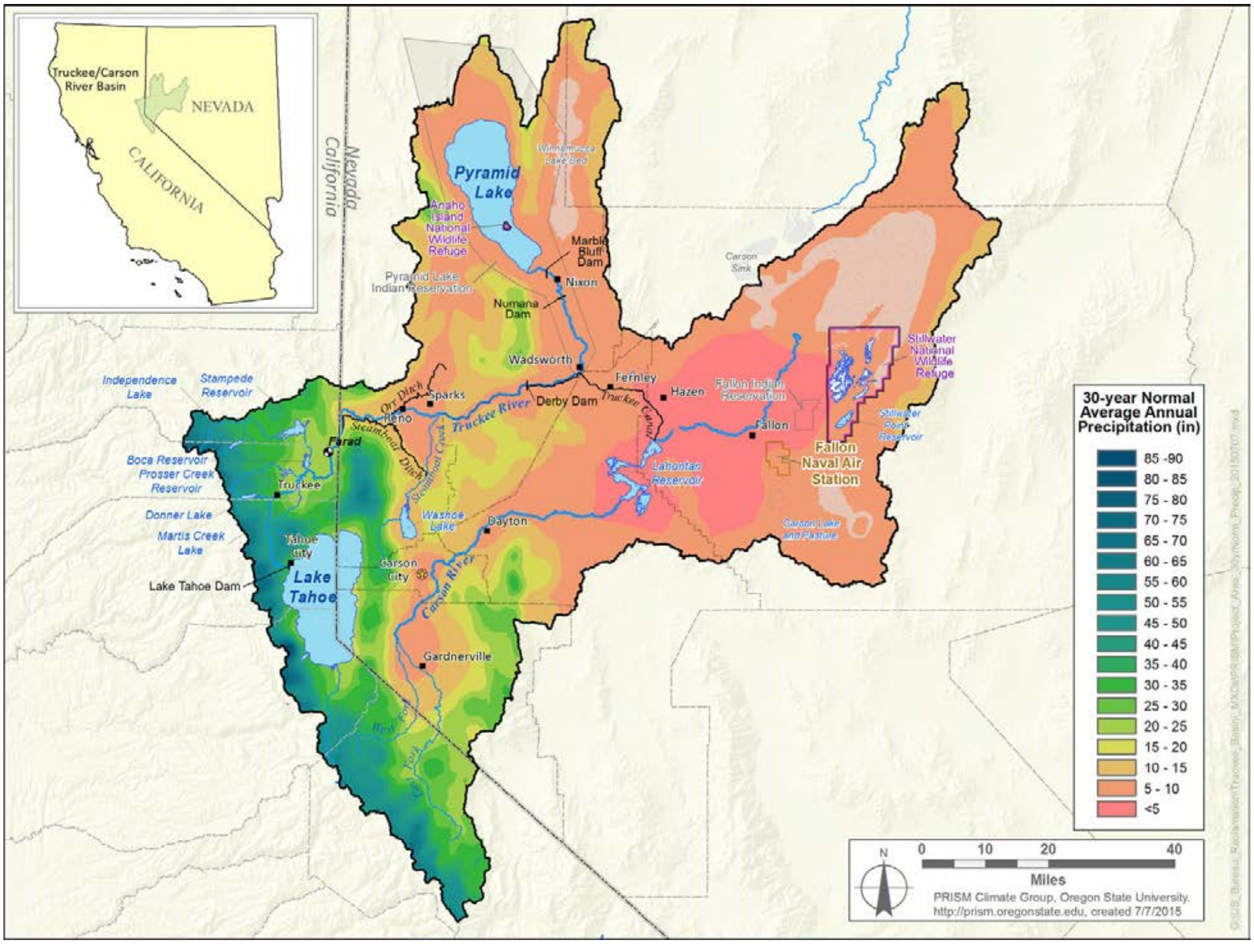


Figure 25. Example sourced from: Truckee Basin Study: Basin Study Report (Reclamation 2015d), *Figure 3-12. Average Annual Precipitation at Reno-Tahoe International Airport (1981-2010)*

Precipitation - Projected

Just as observed precipitation is presented in a time-series data graph type so are precipitation projections, though with the addition of the confidence interval (Figure 26). The confidence interval is a visual representation of the range of uncertainty in the model results. As with the time-series representation of observed precipitation, the “take-away” here would be the significance of the trend. Other display considerations include differentiation between observed and projected values and clarification of what the projected values represent (e.g., the scenario or scenarios being used).

The isopleth map example for observed precipitation (Figure 25) lacked the dimensionality of time, as do most map data graph types. Variation in precipitation over time periods and across climate scenarios can be represented as small multiples to increase dimensionality of data visualization (Figure 27). Displaying data as the change in precipitation as opposed to total precipitation makes differences across time and scenario more apparent.

One part of supply analysis is to translate variation in climate variables into changes in other aspects of the physical systems under study. This could be change in system dynamics such as hydrology (Figure 28) or include potential impacts (Figure 29). The data graph visualization types presented in the Introduction section—***Bar/Column Charts***—are typically employed to convey ***Comparison***.

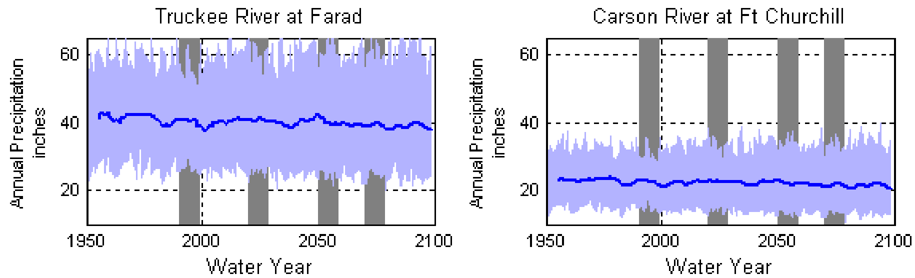


Figure 26. Example sourced from: Truckee Basin Study: Basin Study Report (Reclamation 2015d), *Figure 3-25. Range of Mean Average Annual Precipitation for the Truckee and Carson Basins Through 2100*

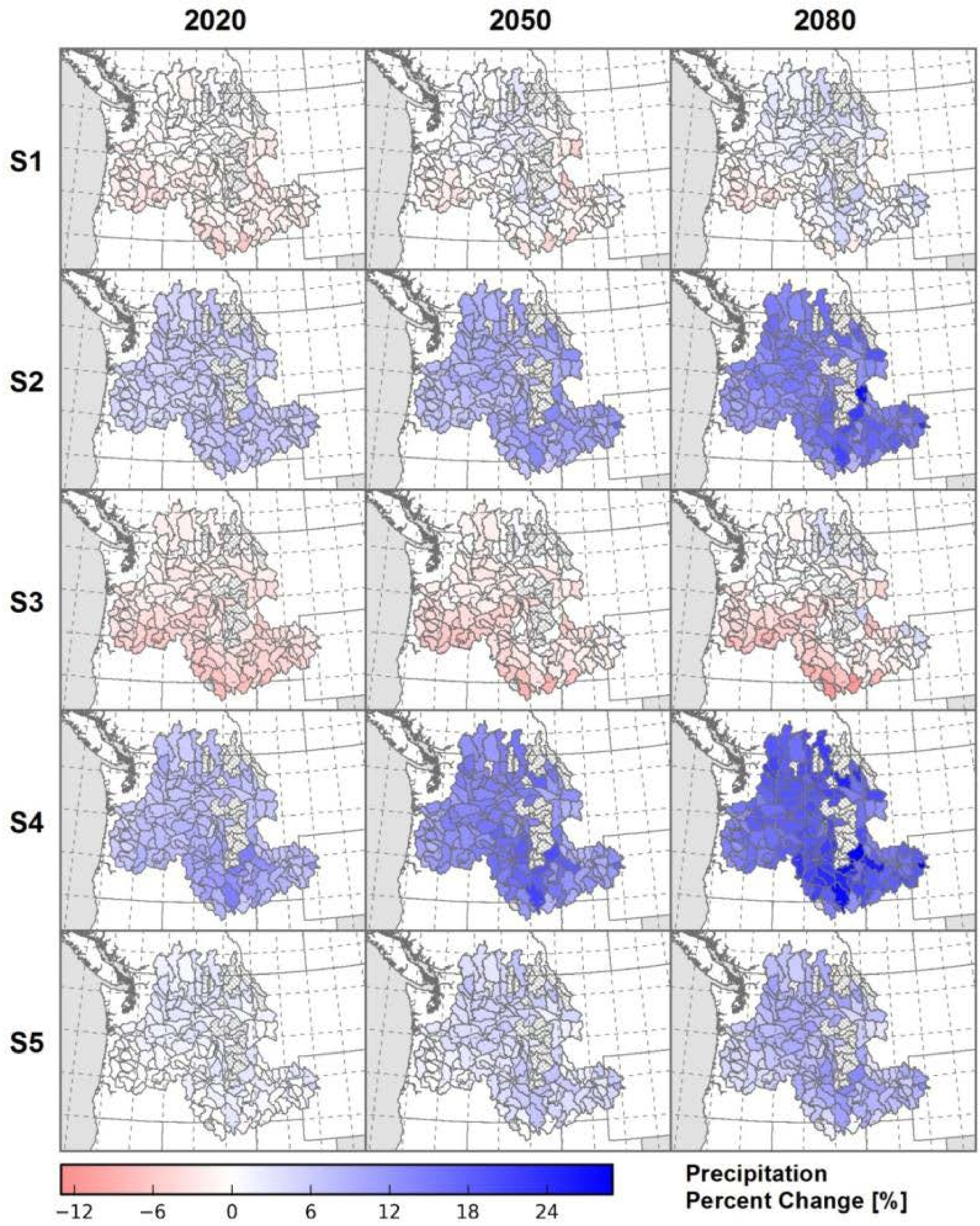


Figure 27. Example sourced from: WWCRA: Irrigation Demand and Reservoir Evaporation Rates (Reclamation 2015a), Figure 31. Columbia River Basin – Spatial distribution of projected precipitation percent change for different climate scenarios and time periods (S1 = WD, S2 = WW, S3 = HD, S4 = HW, S5 = Central).

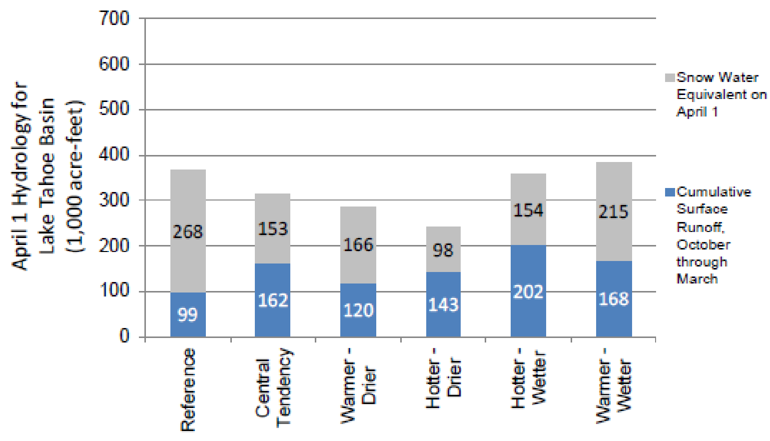


Figure 28. Example sourced from: Truckee Basin Study: Basin Study Report (Reclamation 2015d), Figure 6-5. Comparison of Runoff and Snow Accumulation for the Lake Tahoe Basin (2012 – 2099), by Supply Condition

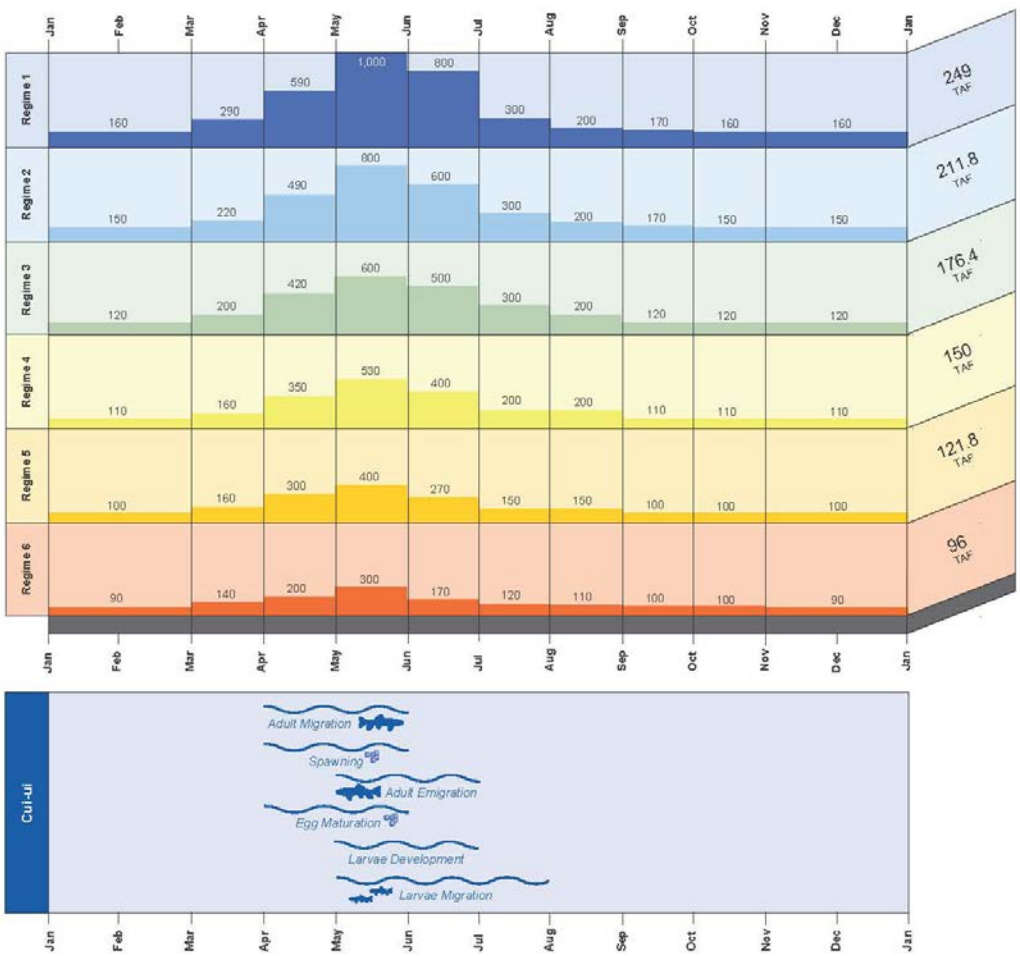


Figure 29. Example sourced from: Truckee Basin Study: Basin Study Report (Reclamation 2015d), ***Figure 5-8. Flow Regimes and Historical Timing of Cui-ui Life Stages***

Precipitation – Redesign Considerations

Data graphs taken from Weather Spark (2016) are presented below as redesign ideas. Figure 30 presents monthly precipitation in rainfall as a time-series graph with confidence interval and snowfall. Figure 31 similarly displays precipitation in snowfall. Figure 32 is an example of using a stacked area graph to show the composition of average monthly precipitation.

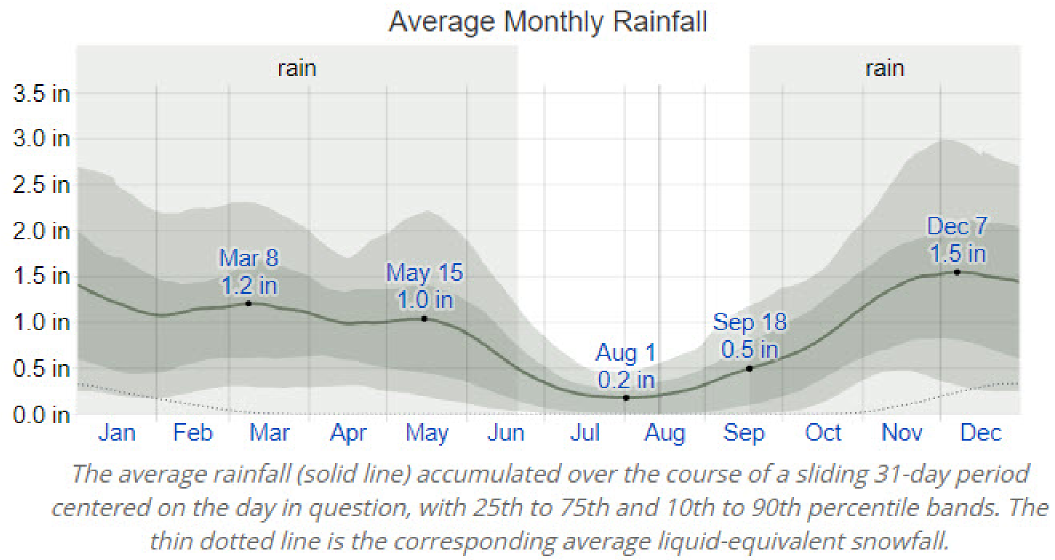


Figure 30. Example sourced from: Weather Spark at https://weatherspark.com/y/2142/Average-Weather-in-Boise-Idaho-United-States-Year-Round

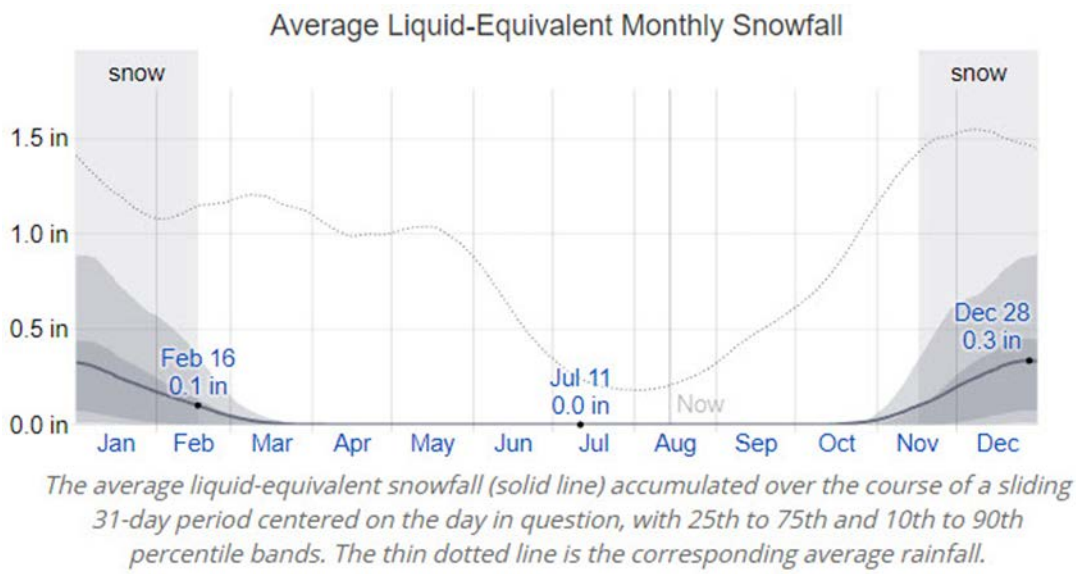


Figure 31. Example sourced from: Weather Spark at https://weatherspark.com/y/2142/Average-Weather-in-Boise-Idaho-United-States-Year-Round

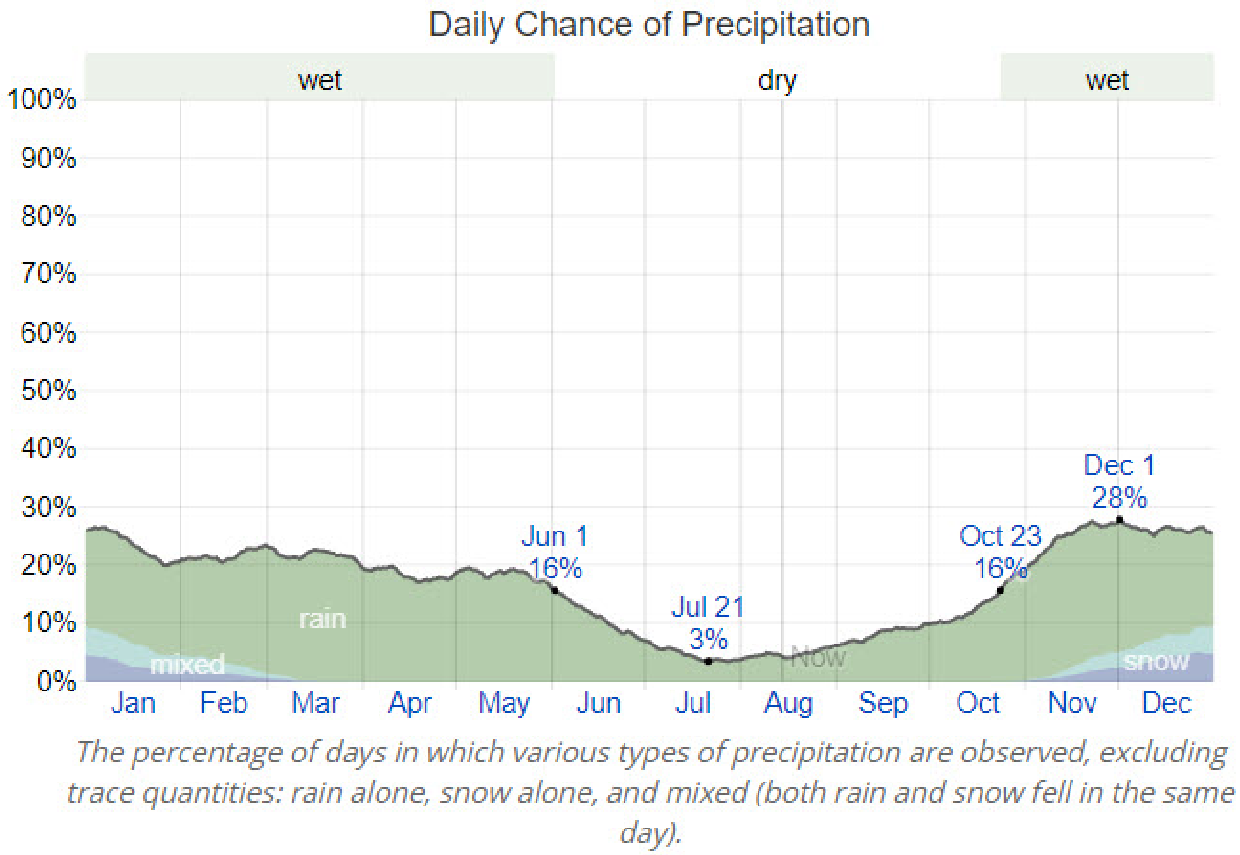


Figure 32. Example sourced from: Weather Spark at https://weatherspark.com/y/2142/Average-Weather-in-Boise-Idaho-United-States-Year-Round

Temperature - Observed

Temperature data is reported similarly to precipitation data, using graphics conducive to time-series, such as line graphs (Figure 33 and 34), histograms (Figure 35), and isopleth maps (Figures 36-38). Because of this similarity, the same redesign principles discussed for precipitation apply to temperature. Figure 39 provides an example of using a box and whisker plot to add dimensionality to the data graph (discrete monthly averages, annual average, and annual distribution). Comparisons between years are made by using multiple box and whisker plots. Figures 34 and 35 provide an example of representing temperature in different ways; either totals or departure from average.

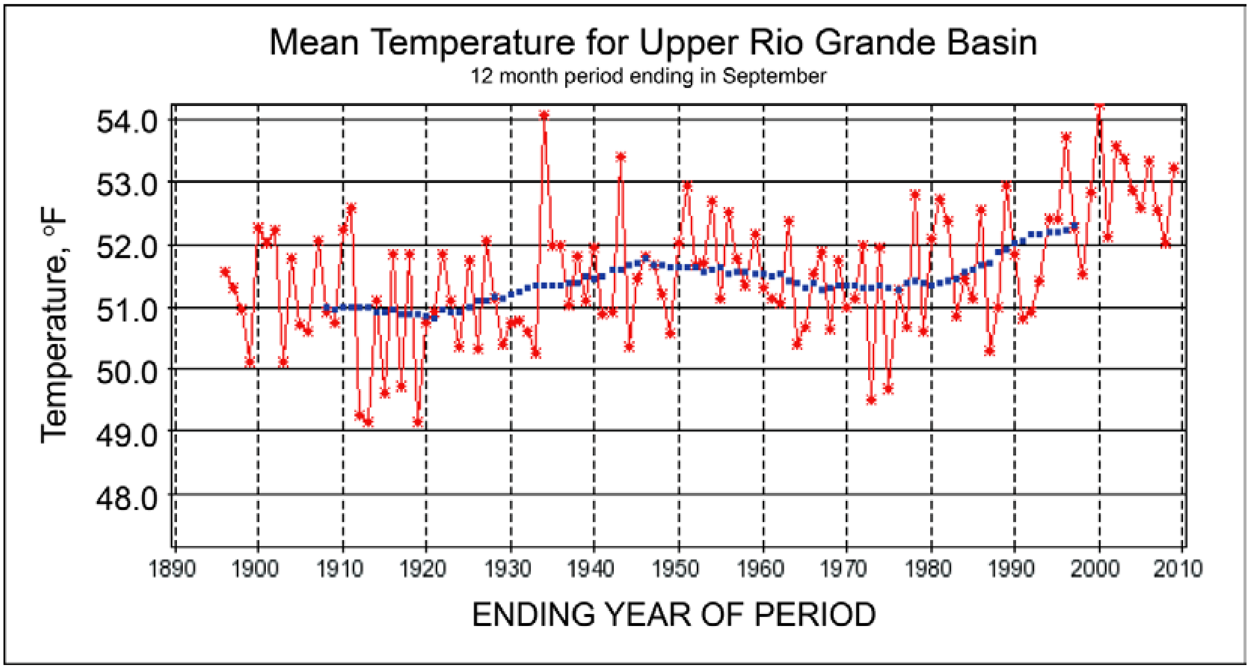


Figure 33. Example sourced from: WWCRA: Upper Rio-Grande Impact Assessment (Reclamation 2013b), Figure 10. Observed annual temperature, averaged over the Upper Rio Grande Basin. Red line indicates annual time series for the given geographic region. Blue line is 25-year moving annual mean.

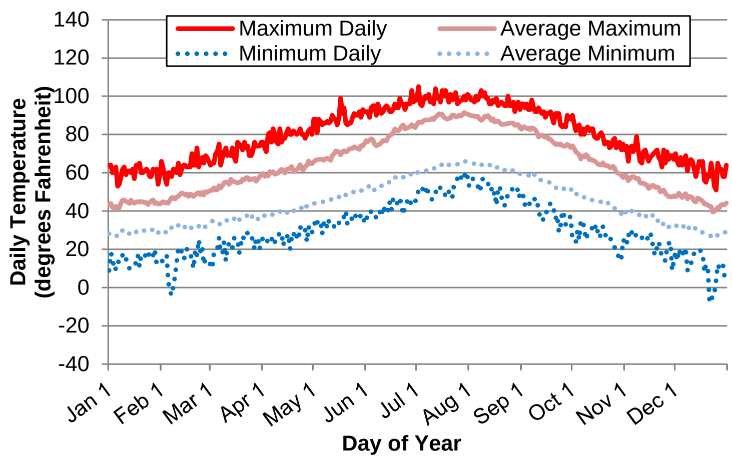


Figure 34. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 3-10. Maximum/Minimum Daily Temperatures at Sutcliff, Nevada (1969–2012)*

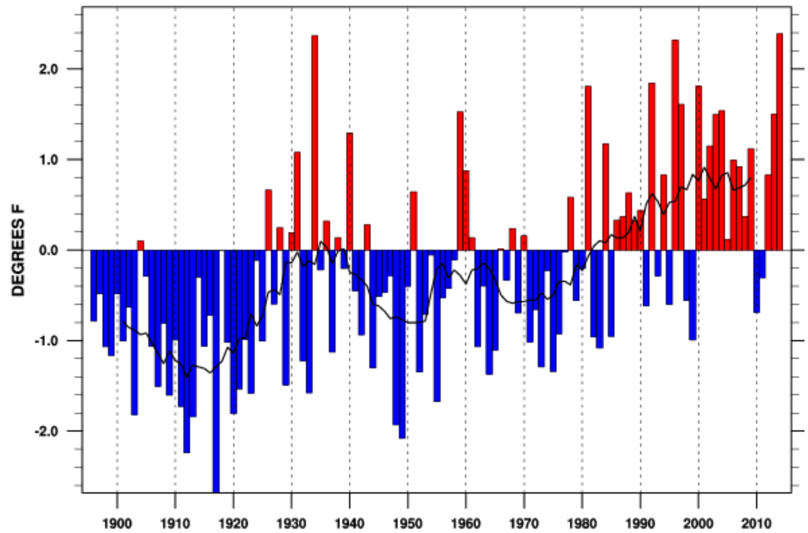


Figure 35. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), Figure 36-3a, California statewide mean temperature departure (Oct-Sep). Notes: Departure of annual water year average surface air temperature for the entire state, 1896-2014. Bars: annual values; solid line: 11-year running mean. Source" Western Regional Climate Center 2015

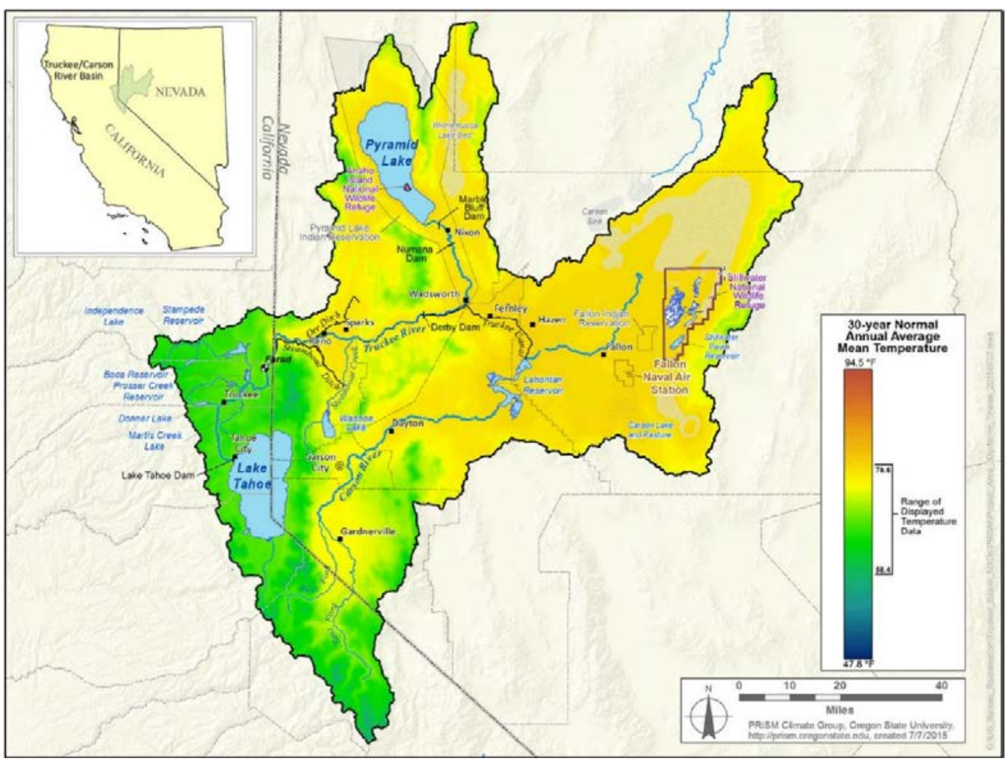


Figure 36. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 3-3. Average Annual Temperatures in Truckee Basin (1981–2010)*

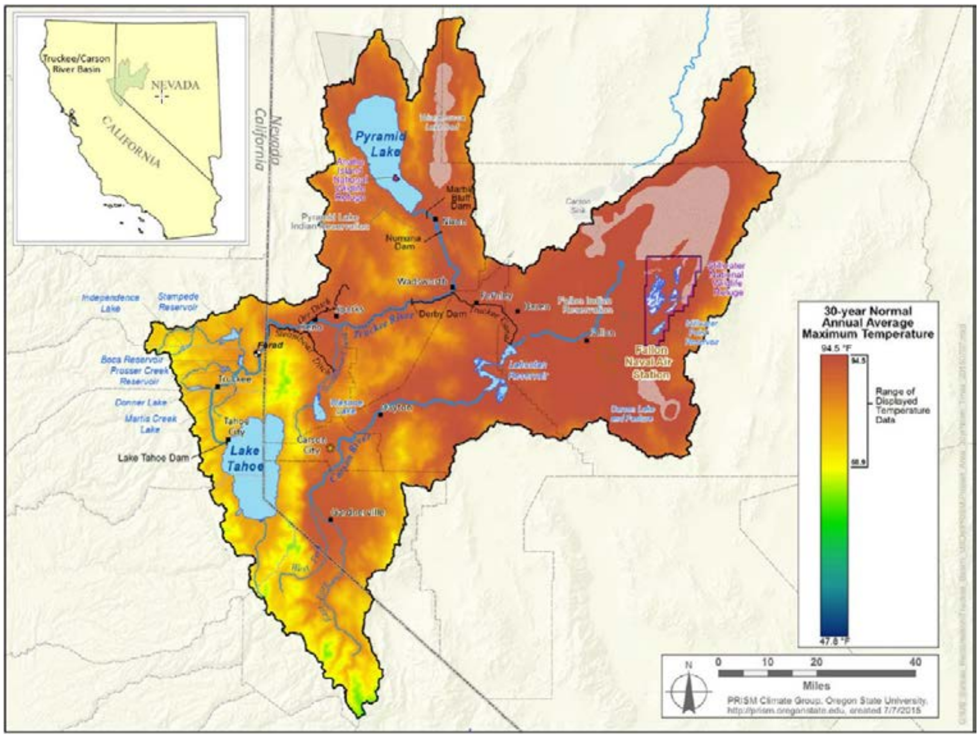


Figure 37. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 3-4. Average Annual Maximum Temperatures in Truckee Basin (1981–2010)*

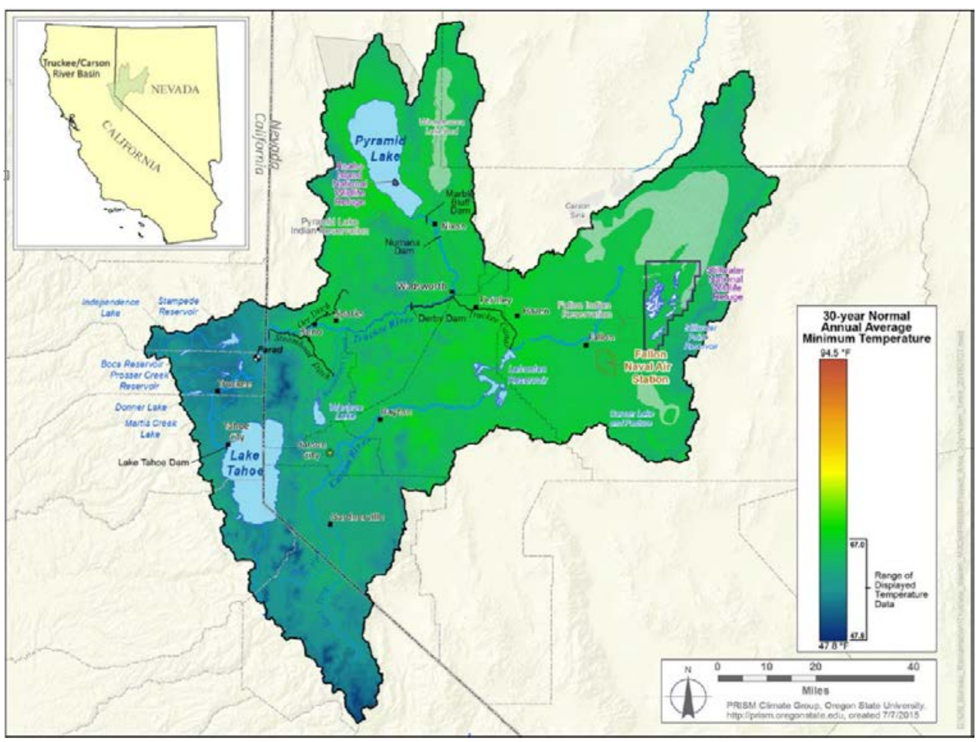


Figure 38. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 3-3. Average Annual Minimum Temperatures in Truckee Basin (1981–2010)*

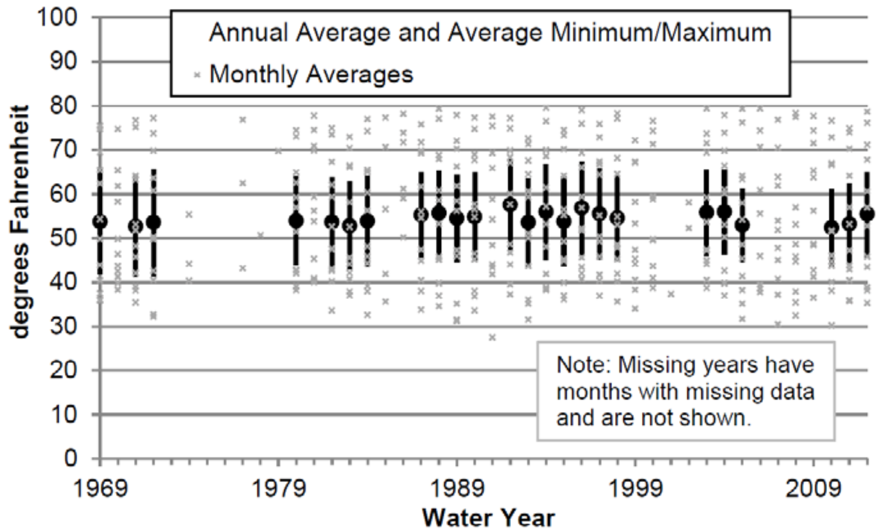


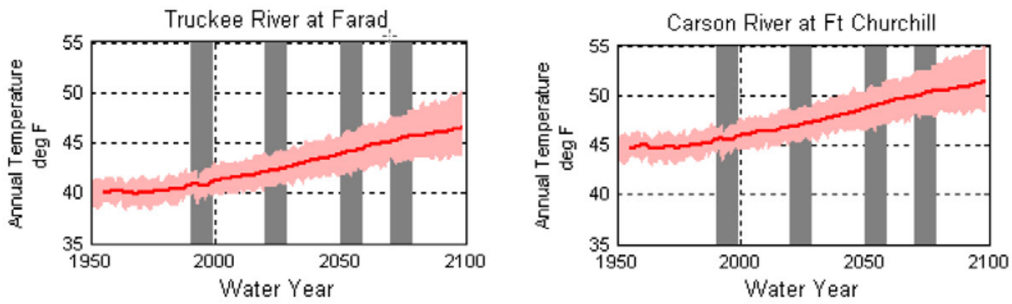
Figure 39. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 3-11. Annual and Monthly Average Temperatures at Sutcliff, Nevada (1969–2012)*

Temperature - Projected

Figures 40 and 41 come from the same source as Figures 26 and 27. Though the latter displayed projected precipitation, the same data graph types are used here, and previous discussion of design applies. Regardless of what is being displayed, whether temperature or precipitation, design principles and guideline apply to the display (i.e., data graph) itself. Variation in how the data graph is displayed depends on the information being presented.

Some Reclamation studies report precipitation and temperature sequentially (as in the previous examples) while others analyze and report precipitation and temperature in tandem (as in the Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e)). reports precipitation and temperature in tandem and in terms of absolute and change values. The data graphs are presented in groups as: *Figure 2-4. Temperature and precipitation projections* and *Figure 2-5. Temperature and precipitation change in ensemble climate scenarios* with subgroups *a* and *b*.

Figures 42 and 43 are time-series data graph types using multiple line graphs. Each line graph is a time-series representation for a scenario and multiples are presented to draw comparisons between scenarios. The use of multiple line graphs in a single data visualization can result in obscured data representations (e.g., RF in Figure 43 is nearly absent from view). Separate data graphs for each scenario would present unobscured features and allow comparison between graphs; in the case of this example, for each scenario (WD, HD, HW, WW, and CEN). For each data graph, an emphasized scenario and a muted symbology for the rest of the scenarios would maintain data dimensionality through small multiples.



Source: Reclamation 2011a

Figure 40. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), Figure 3-24. Range of Mean Average Annual Temperatures Projected for the Truckee and Carson Basins Through 2100

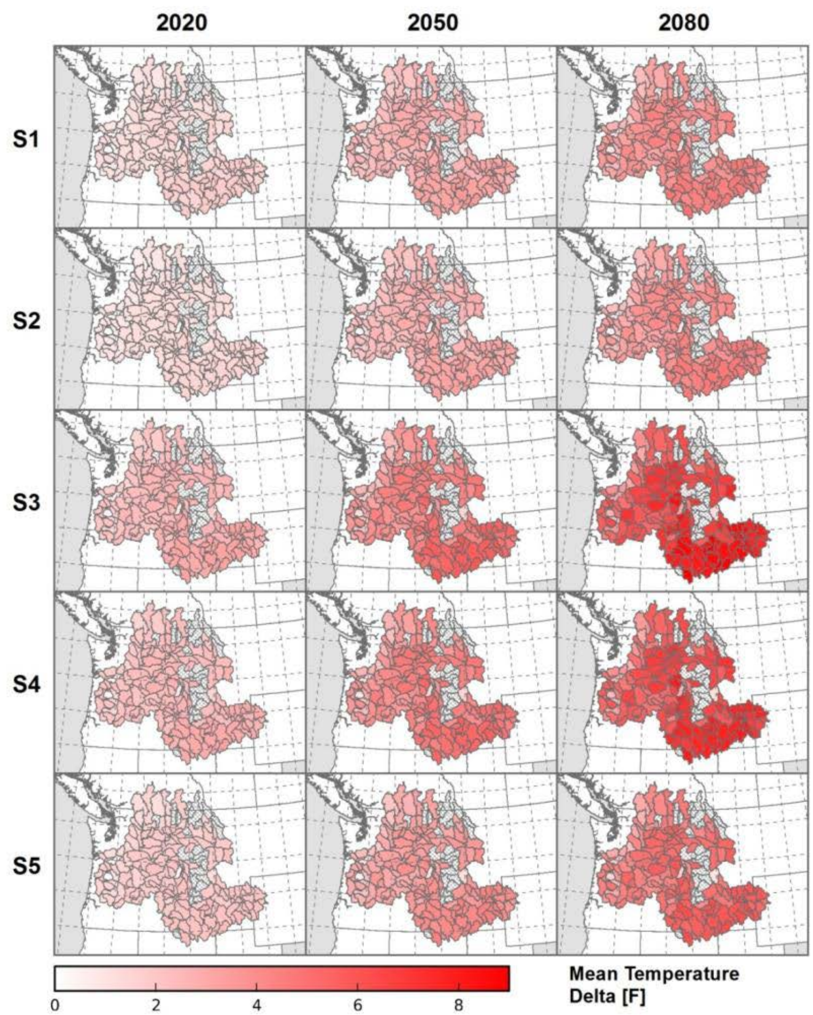


Figure 41. Example sourced from: WWCRA: Irrigation Demand and Reservoir Evaporation Rates (Reclamation 2015a), Figure 30. Columbia River Basin – Spatial distribution of temperature change for different climate scenarios and time periods (S1 = WD, S2 = WW, S3 = HD, S4 = HW, S5 = Central).

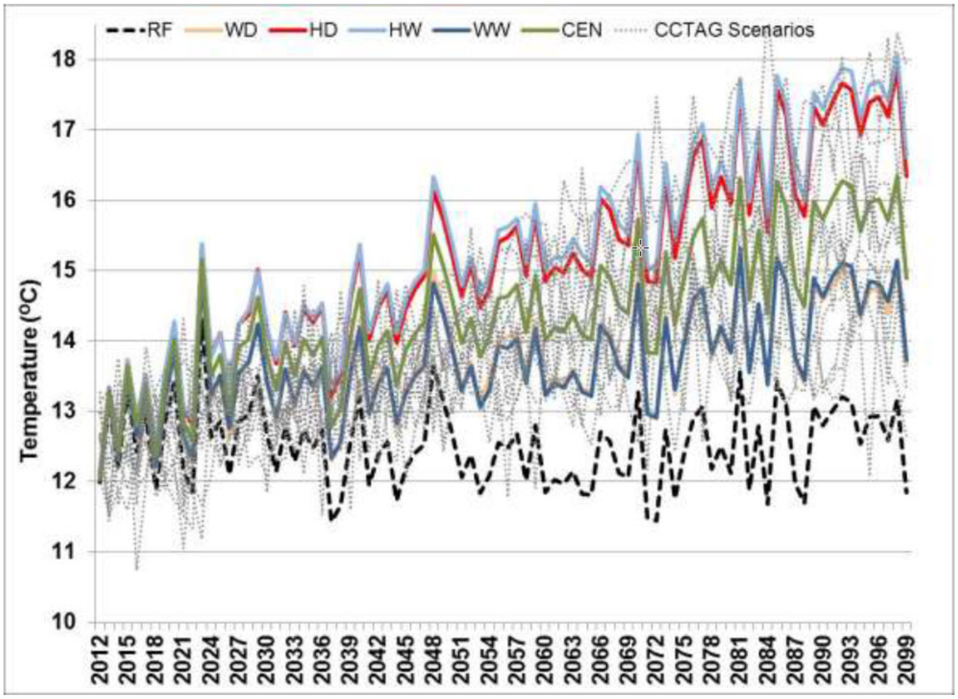


Figure 42. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), ***Figure 2-4a. Temperature projections under each climate scenario for the Sacramento River hydrologic region***

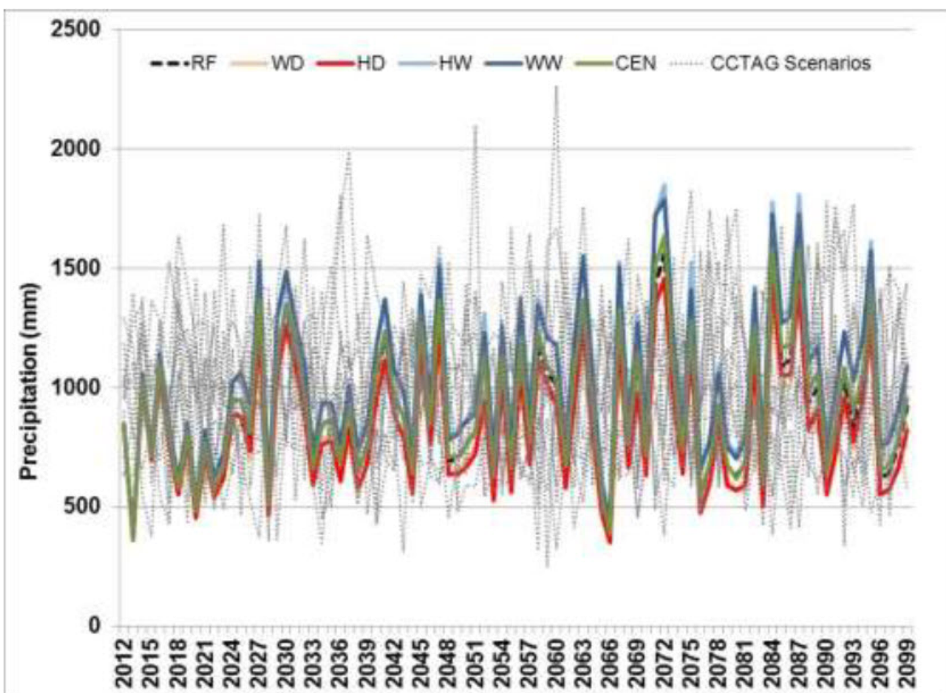


Figure 43. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), Figure 2-4b. Precipitation projections under each climate scenario for the Sacramento River hydrologic region

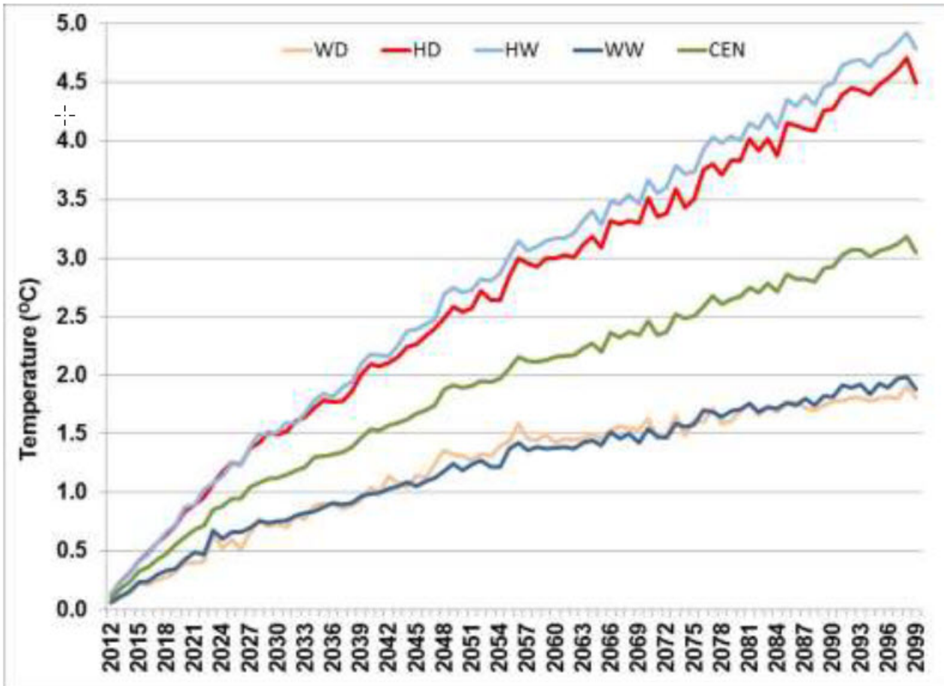


Figure 44. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), Figure 2-5a. Projected changes in temperature for ensemble climate scenarios for Sacramento River hydrologic region

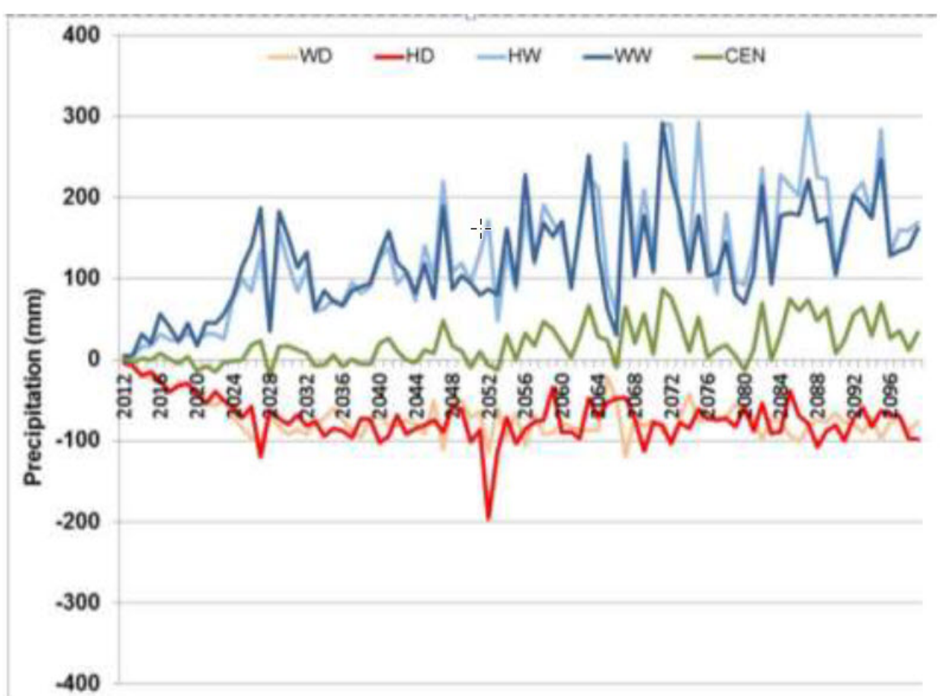


Figure 45. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), Figure 2-5b. Projected changes in precipitation for ensemble transient climate scenarios for Sacramento River hydrologic region

Precipitation and Temperature – Redesign Considerations

Tufte presents the New York history data visualization (Figure 46) as an example of a high-resolution time-series data graphic in *The Visual Display of Quantitative Information* (Tufte 2015) and his blog (Tufte n.d.). A blog comment recommended displaying precipitation as columns rather than an area graph. However, precipitation and temperature are related in impacting water supply, so rather than presenting the information in separate data graphs, the New York example consolidates the information for a reader wanting a larger overview of a study's reporting.

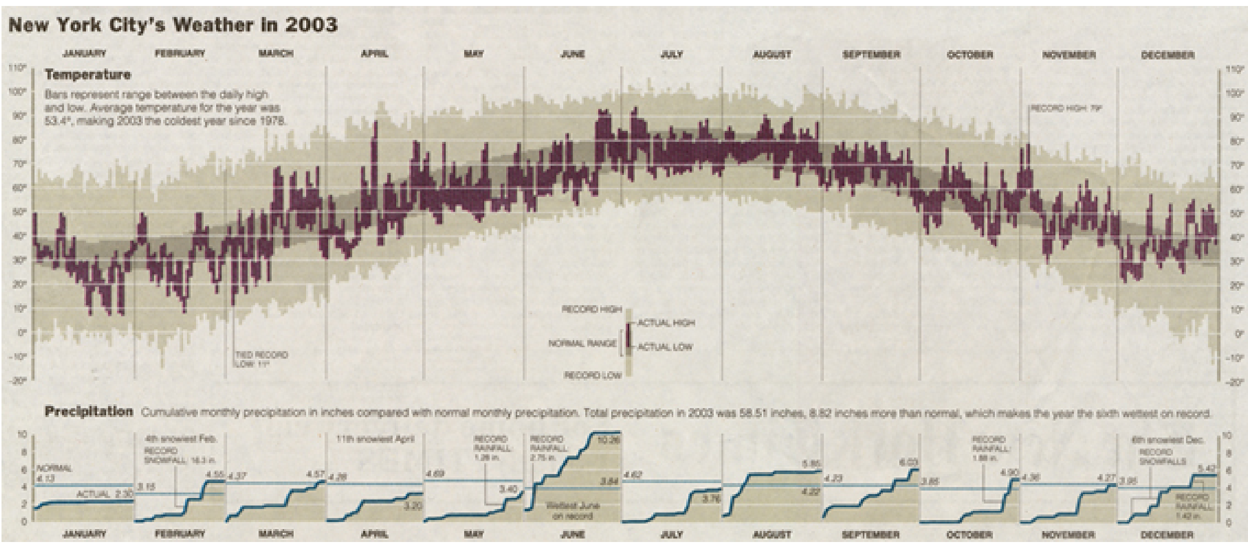
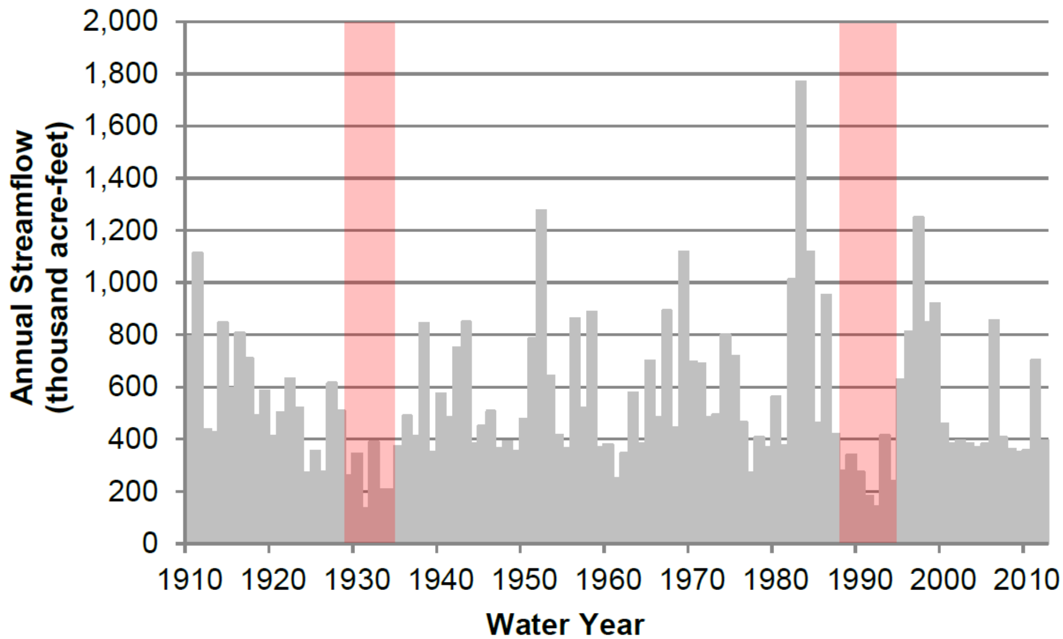


Figure 46. Example sourced from: ET notebooks at https://www.edwardtufte.com/bboard/q-and-a-fetch-msg?msg_id=00014g

Streamflow and Runoff; Storage Inflow - Observed

Another variable of physical systems commonly represented with time-series data graph types is flow, in terms of stream network, runoff, or inflow into reservoirs (Figures 47 through 56). Several of the following examples (Figures 48, 53, and 54) present combinations of data graph types in a single data visualization. Though basically the same information, these examples demonstrate how the data can be represented in various ways. Figure 58 departs from the more typical application of time-series data graph types in presenting a flow chart/illustrative diagram that conceptualizes system components and dynamics.



Note: Red shading indicates the two most severe recorded drought periods in the Truckee Basin.

Figure 47. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), ***Figure 3-19. Annual Gaged Streamflow in Truckee River at Farad (Water Years 1910-2012)***

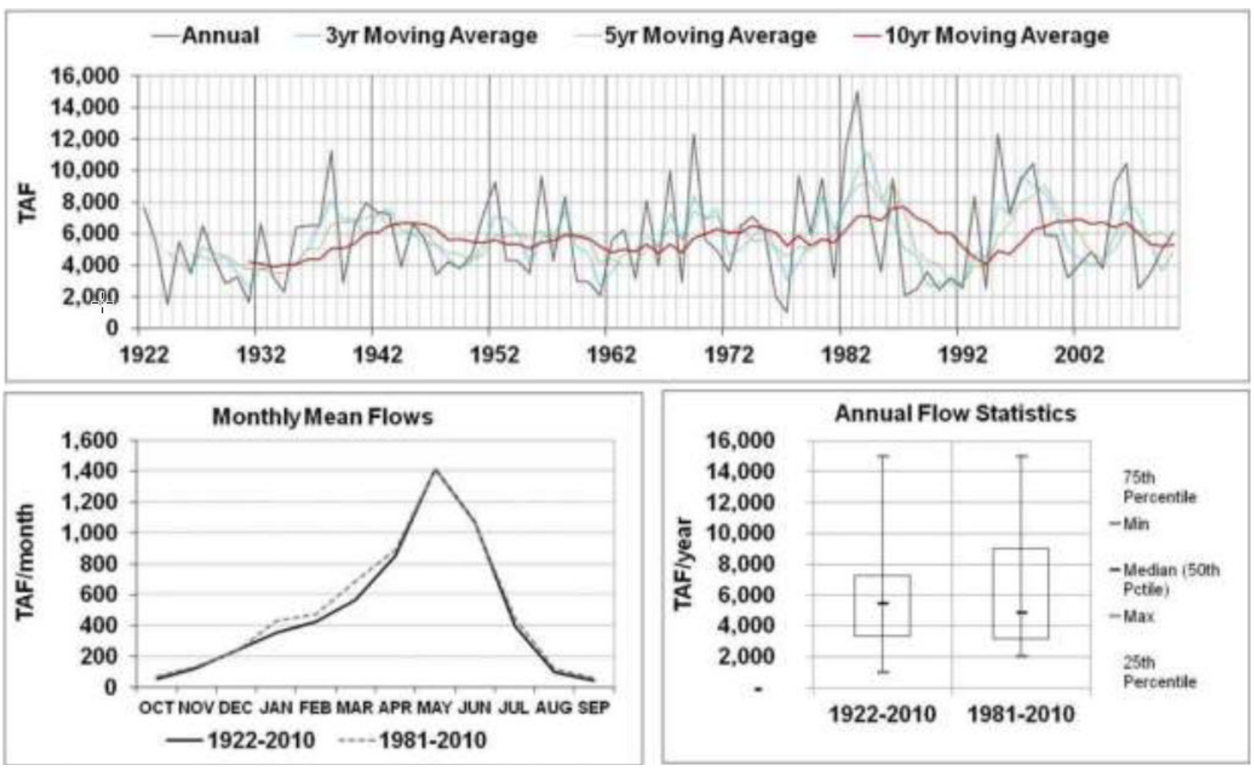


Figure 48. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), ***Figure 3-17c. San Joaquin 4 Rivers Index natural streamflow snapshot analysis***

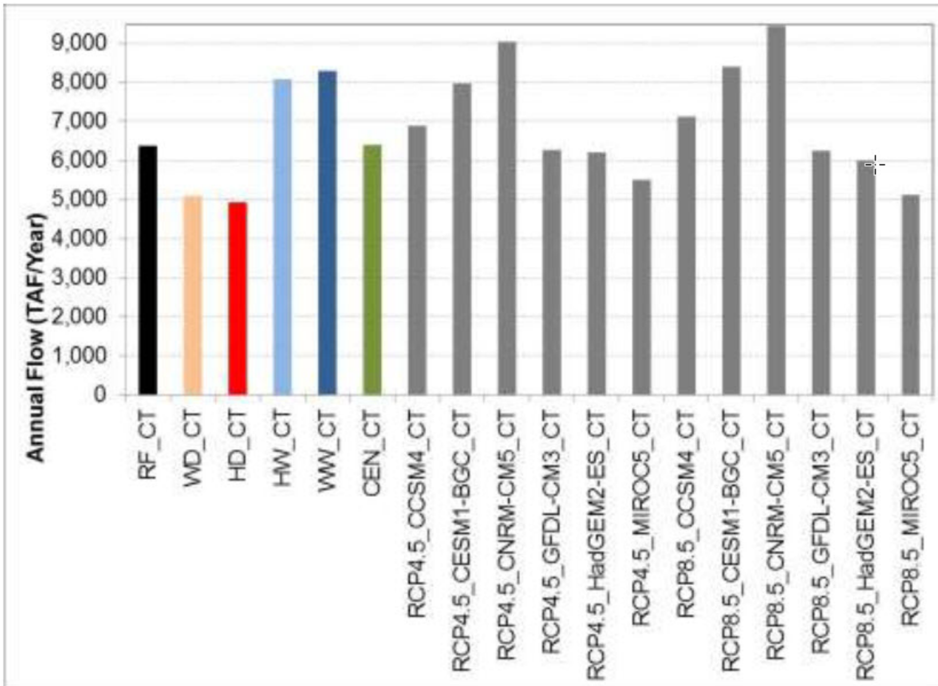


Figure 49. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), Figure 3-18c. Projected average annual streamflow in the San Joaquin River System in each scenario (water years 2015 – 2099)

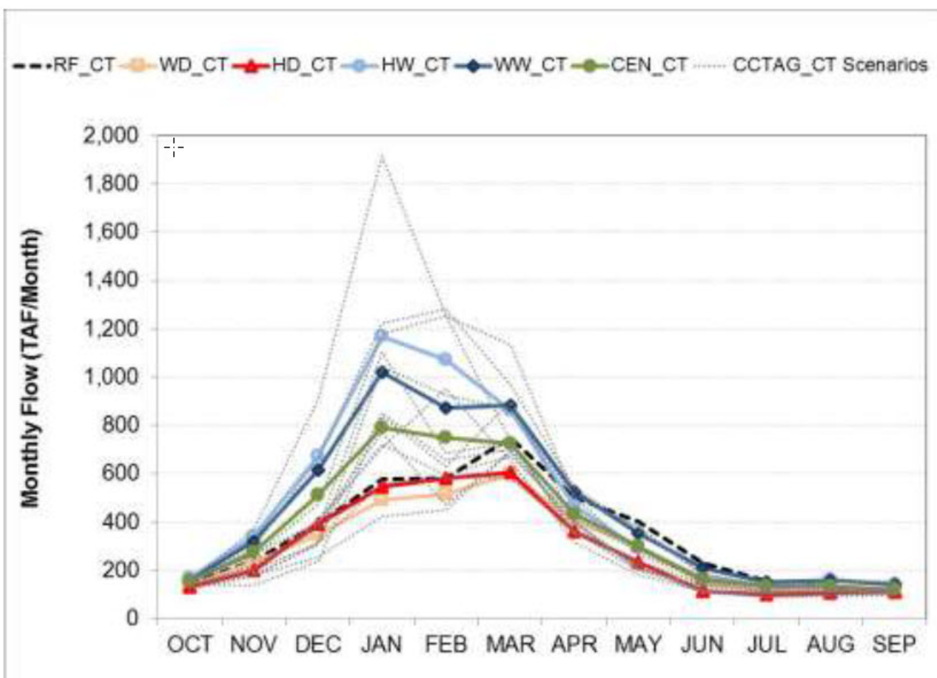


Figure 50. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), Figure 3-19f. Projected average streamflow in each month into Lake Oroville in each climate scenario (long-term average over water years 2070 through 2099).

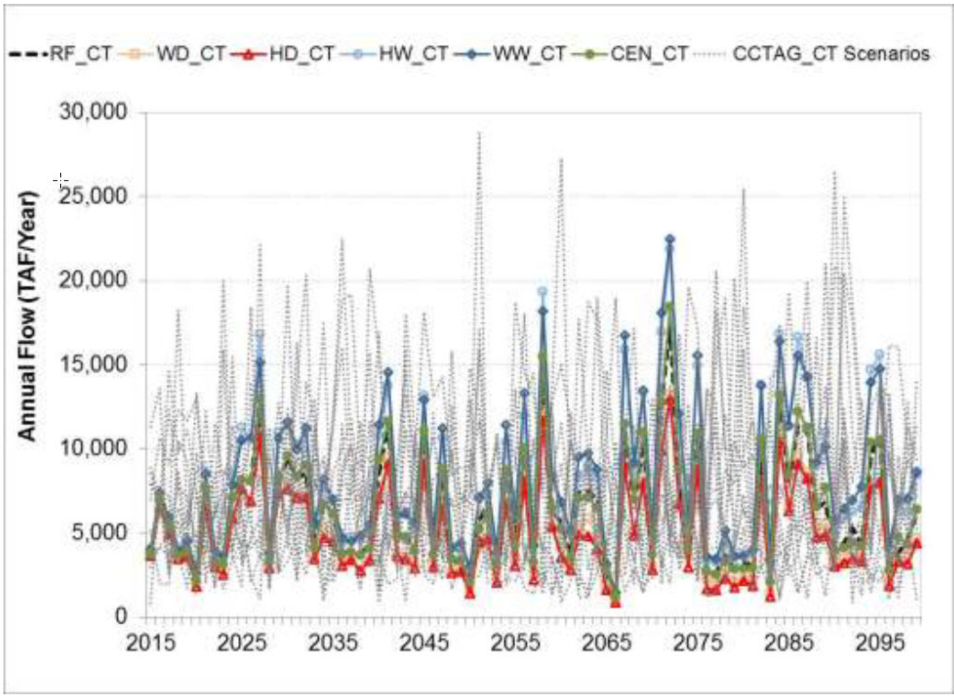


Figure 51. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), Figure 3-20c. Projected annual time series of streamflow in the San Joaquin River system in each climate scenario.

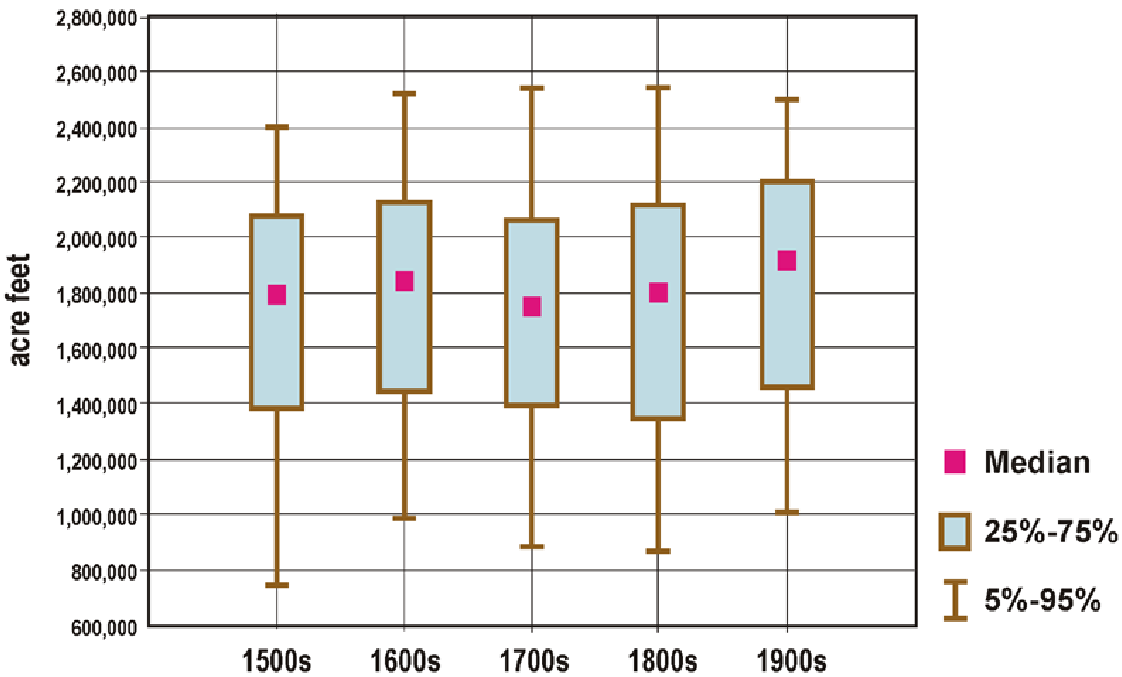


Figure 52. Example sourced from: WWCRA: Upper Rio Grande Impact Assessment (Reclamation 2013b), Figure 6. A box and whisker plot of the Otowi natural flow reconstruction distributed for annual flows in each century (Lukas 2008).

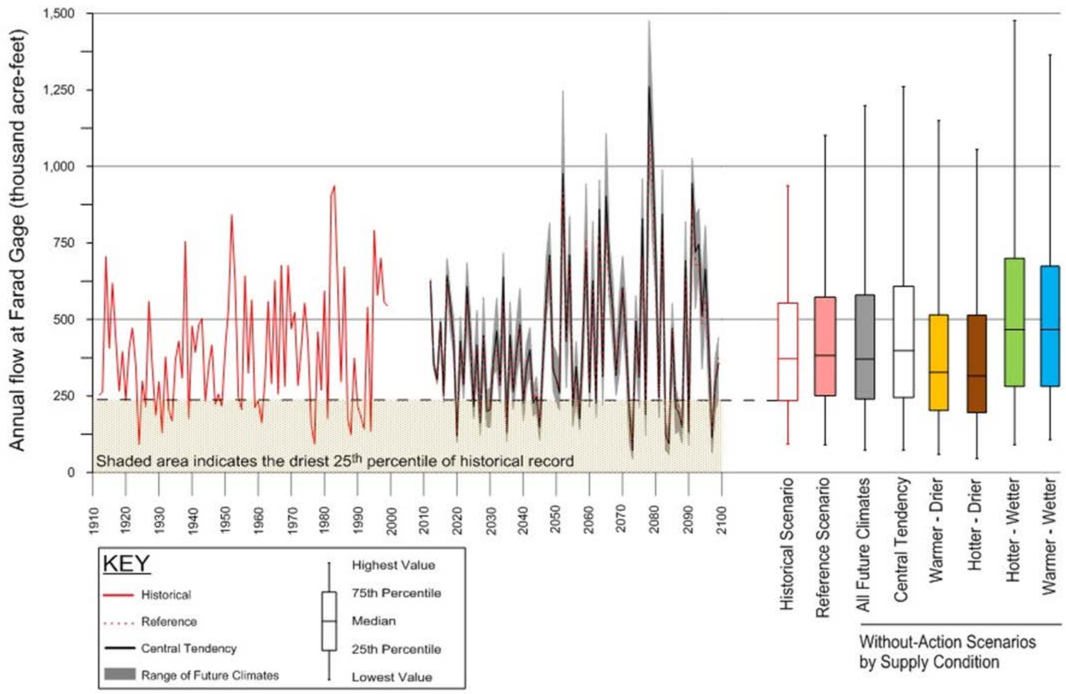


Figure 53. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 6-2. Comparison of Natural Flows at the Farad Gage, Excluding Lake Tahoe*

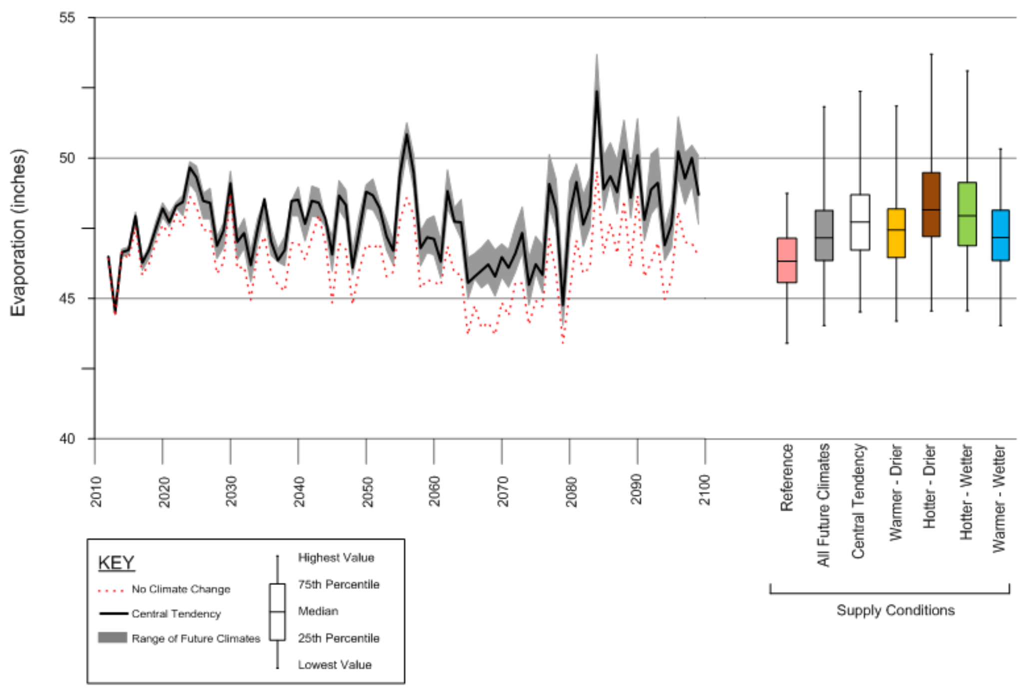


Figure 54. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 3-38. Comparison of Future Annual Evaporation Rates from Lake Tahoe.*

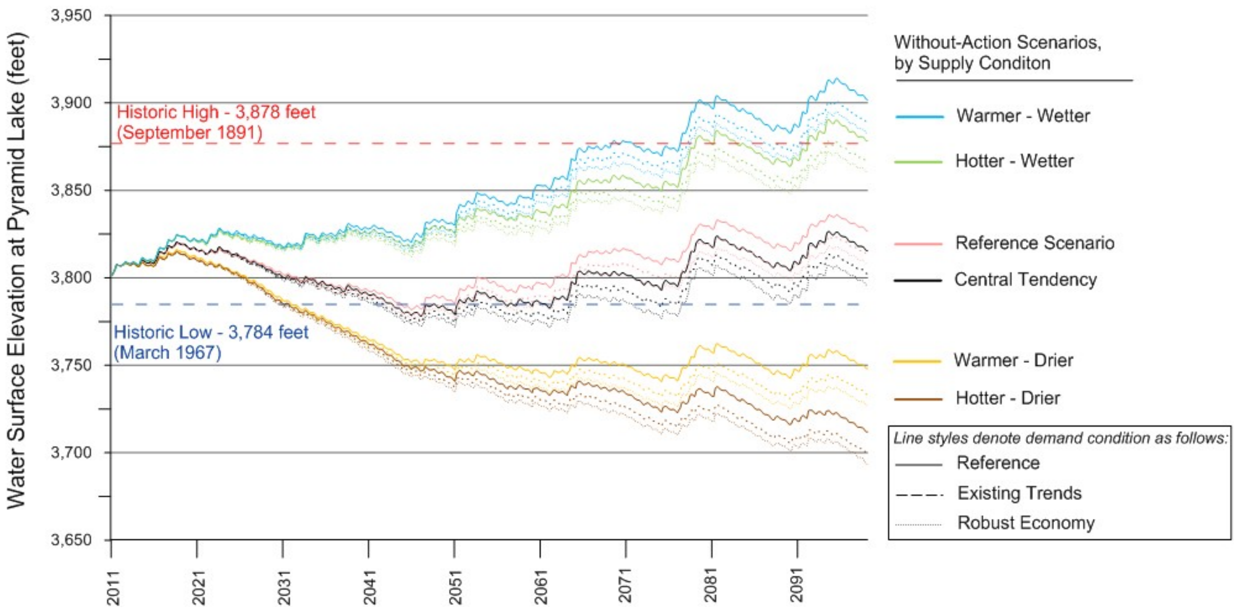


Figure 55. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), Figure 6-1. Projected Future Water Surface Elevations at Pyramid Lake Under Different Scenarios

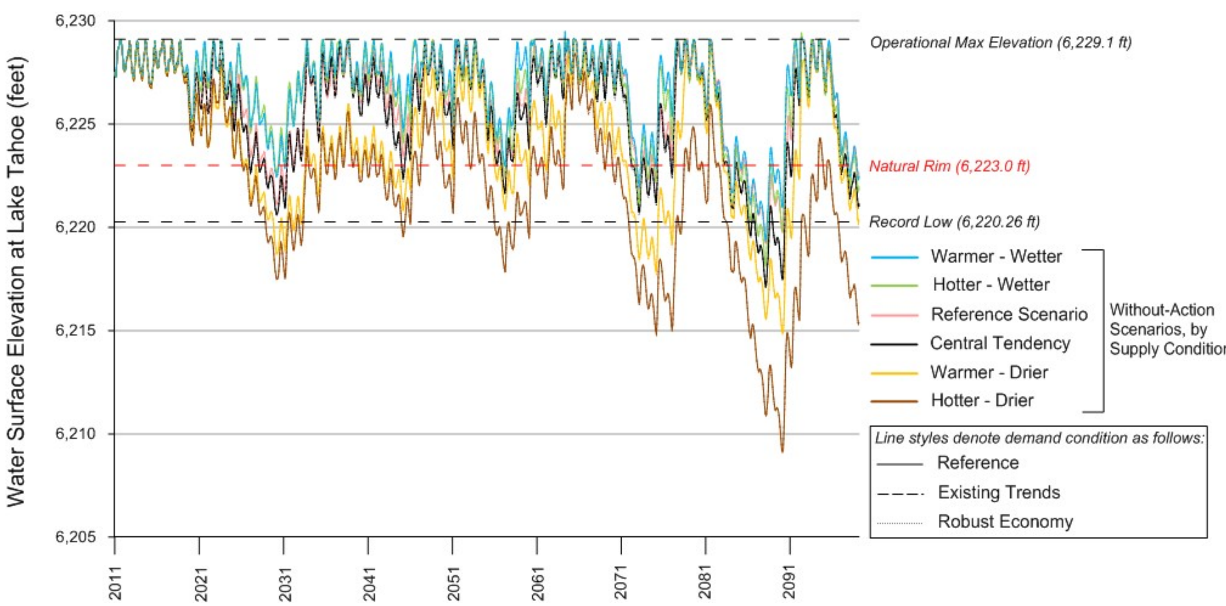


Figure 56. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 6-4. Projected Future Water Surface Elevation at Lake Tahoe*

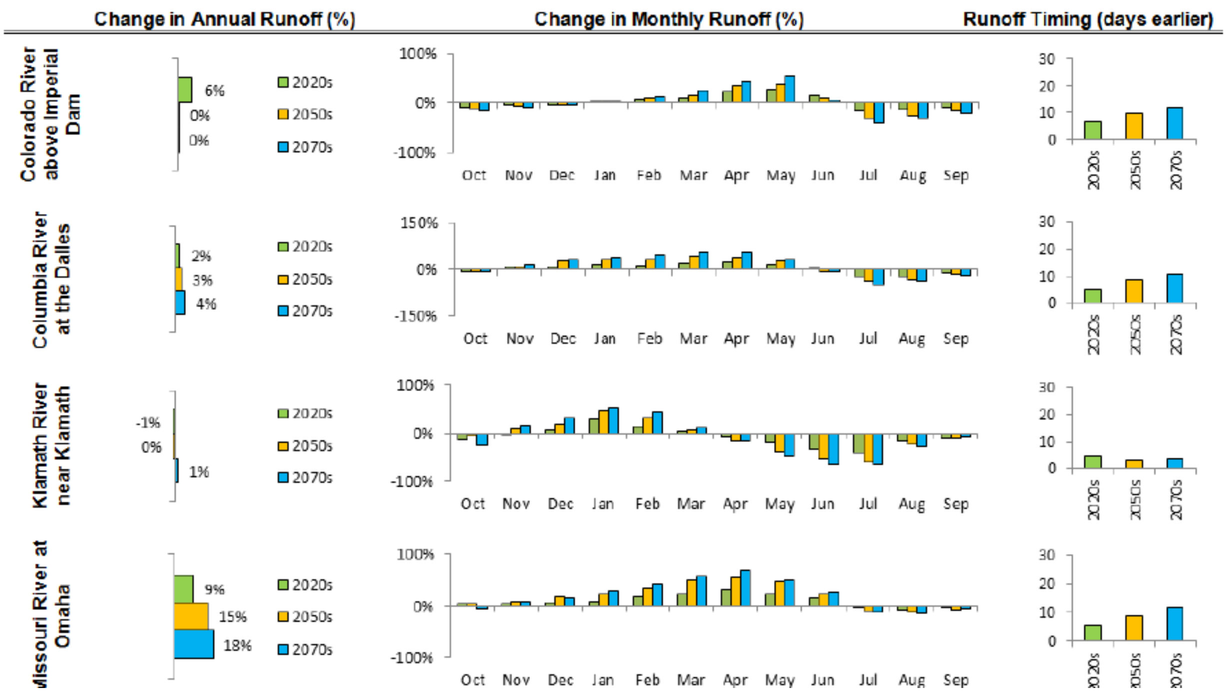


Figure 57. Example sourced from: SECURE Water Act Section 9503© Report to Congress (Reclamation 2016f), Figure 2-4. Projected shift in annual runoff, monthly runoff, and peak runoff date relative to the 1990s for the 2020s, 2050s, and 20270s in the major Reclamation river basins.

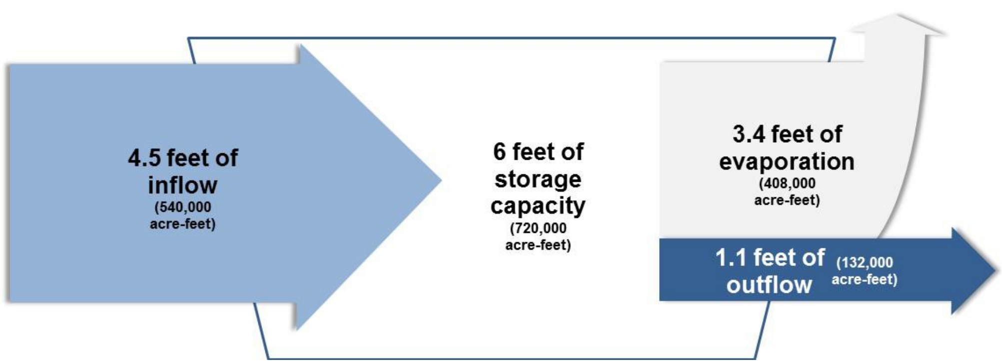


Figure 58. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), Figure 6-3. Average Relationship Between Inflow, Evaporative Losses, and Outflow at Lake Tahoe for the Reference Scenario Truckee

Supply and Demand

Analyses referenced up to this point have focused on projected changes to physical systems; system dynamics. Such analyses allow for assessing the availability and use of resources. Resource supply and demand, and how the resource is allocated or distributed, is likely to be the subject of prime interest, and emphasized in information products other than the technical reports.

Supply and demand analyses typically use data graph types ***Bar/Column Chart***, ***Line Graph***, and ***Stacked Area Graph*** to convey data representation functions ***Comparison***, ***Time Series***, and ***Composition*** (Figures 59 through 63).

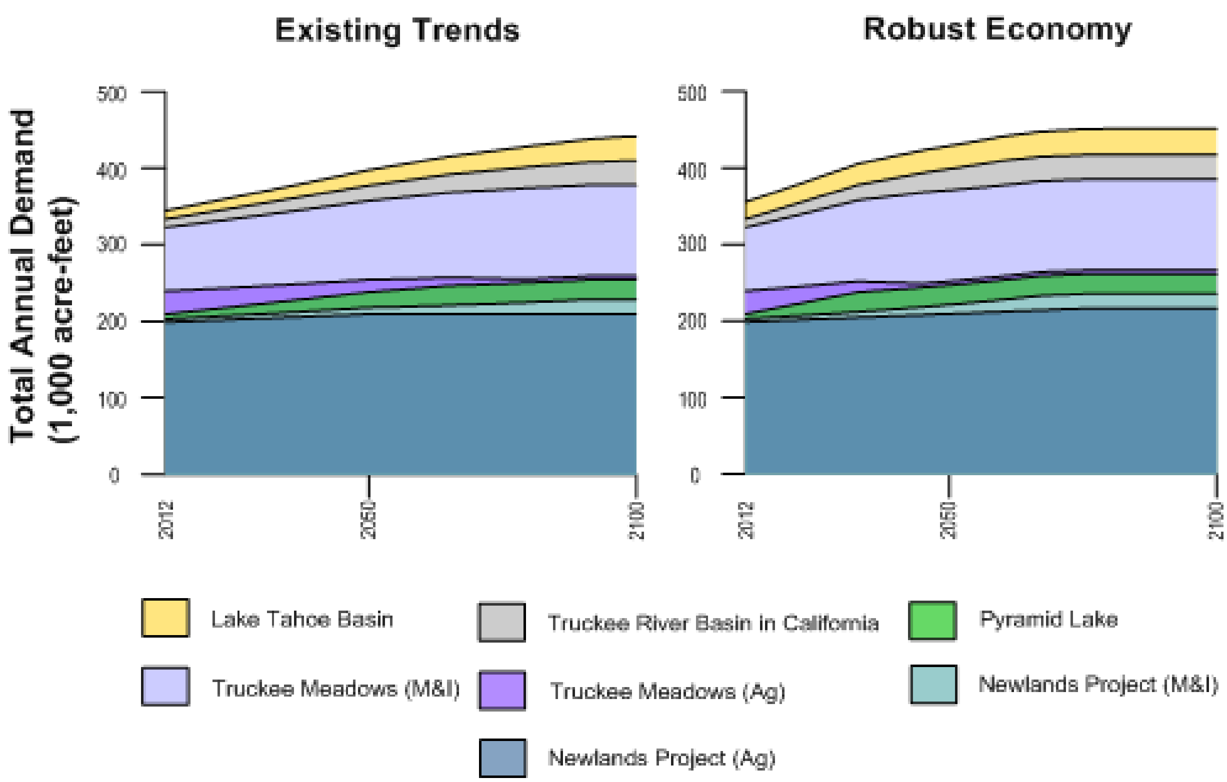


Figure 59. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), *Figure 4-7. Total Truckee basin water demand under future storylines*.

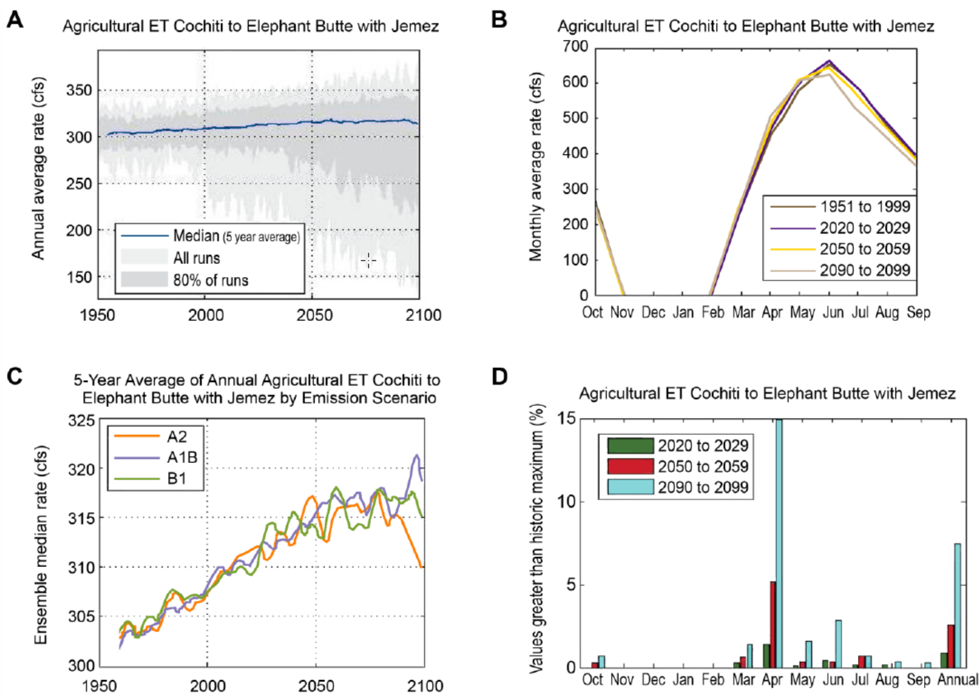


Figure 60. Example sourced from: WWCRA: Upper Rio Grande Impact Assessment (Reclamation 2013b), Figure 37. Total projected crop consumption between Cochiti and Elephant Butte Reservoirs, including the Jemez River valley

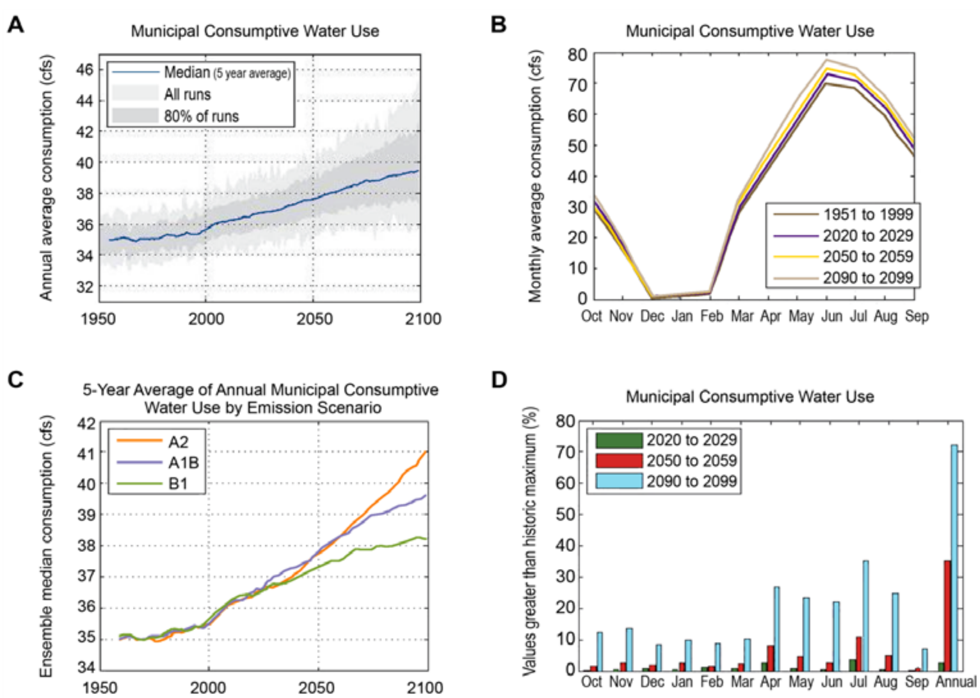


Figure 61. Example sourced from: WWCRA: Upper Rio Grande Impact Assessment (Reclamation 2013b), *Figure 39. Simulated municipal consumptive use*

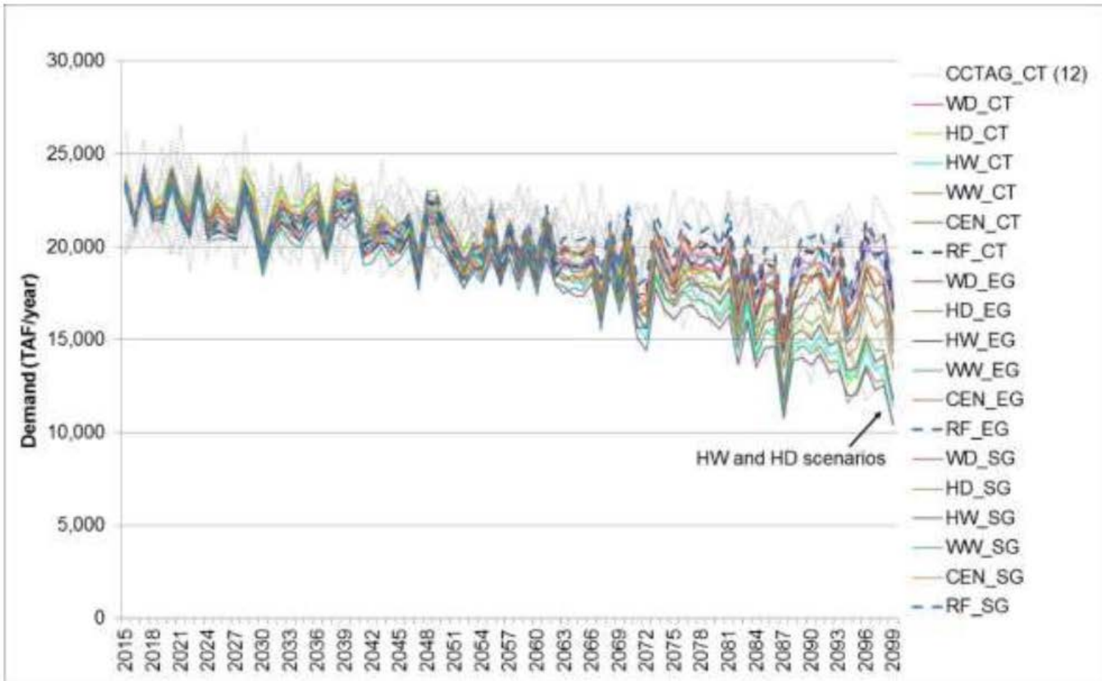


Figure 62. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), ***Figure 4-2a. Annual time series of agricultural applied water demand in the Central Valley in each scenario.***

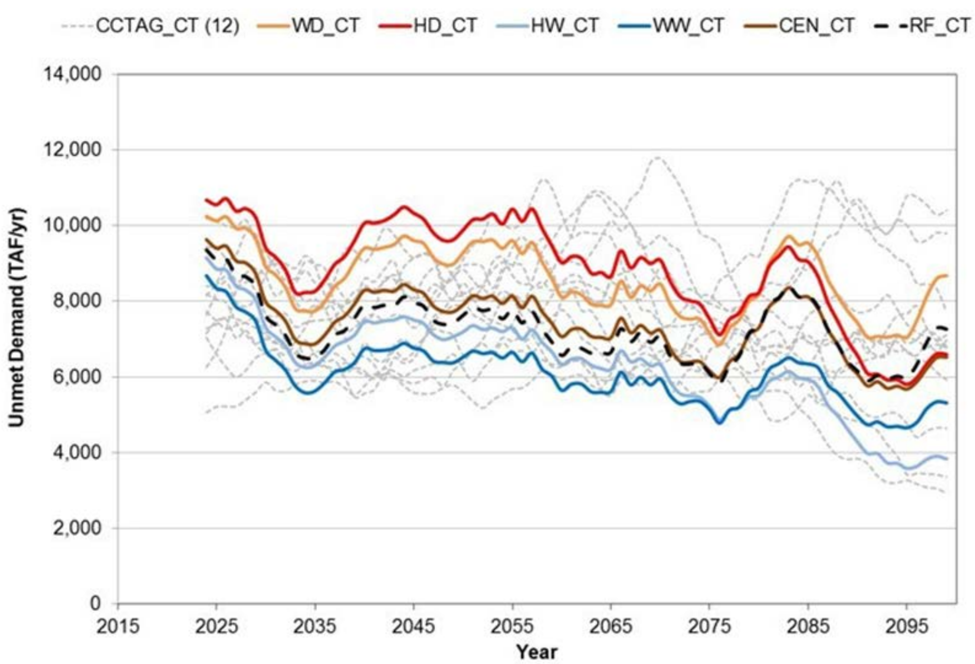


Figure 63. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), Figure 5-3a. 10-year running average of unmet demand in the Central Valley in each climate scenario under the Current Trends socioeconomic scenario.

Supply and Demand Considerations – Redesign Considerations

The Sankey diagram is a useful data visualization for the display of flow within a network and should be considered for use in Reclamation reports. The diagram is named for Matthew H. P. R. Sankey—acknowledged as having been the first to present this data graph type (Sankey 1896). This data graph type was actually first conceptualized by Charles Joseph Minard in his diagram of Napoleon's Russian Campaign of 1812; oft referenced and highly praised by Tufte (1983).

The following example comes from Willamette Water 2100 (INR n.d.). It is presented as a screen shot of an interactive map that displays annual, seasonal, and monthly water budgets for simulated historical and three other climate scenarios.

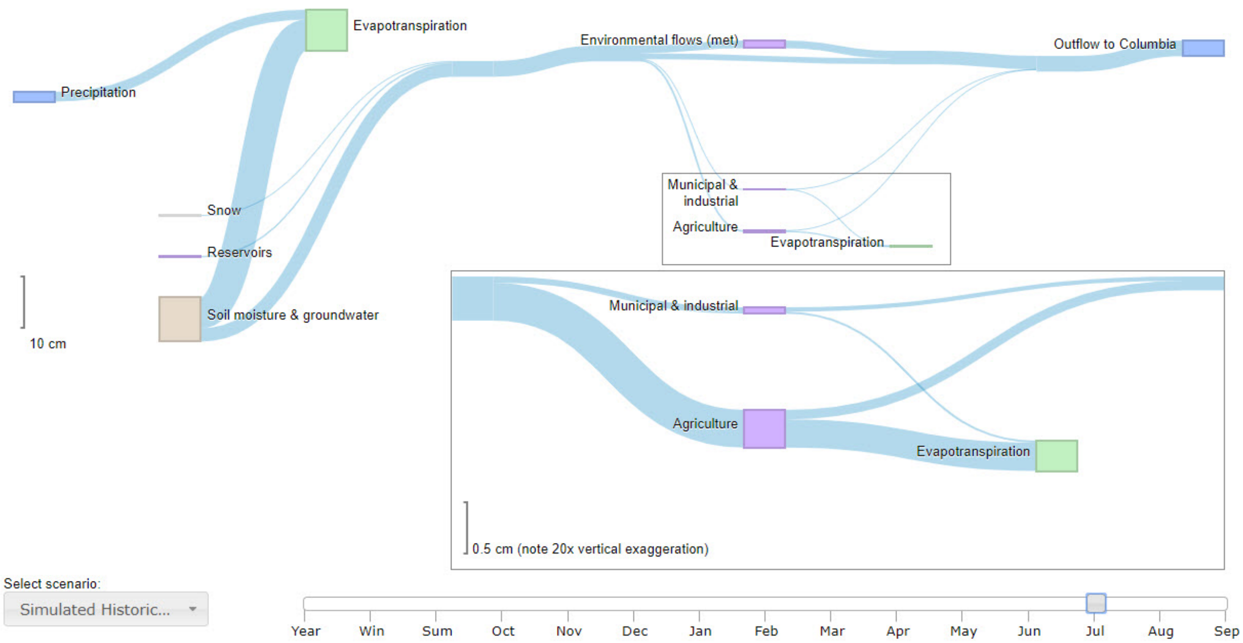


Figure 64. Example of Sankey diagram sourced from: http://inr.oregonstate.edu/ww2100/analysis-topic/hydrology, *WW2100 Interactive Water Budget.* *http://hydro-prod.library.oregonstate.edu/figures/willamette_flows/waterchart.html*

Despite its usefulness and applicability in Reclamation reports, the issue is in acquiring software programs to produce this data graph type. Commercial software is available at a cost. Free open source applications must be cleared through IT security. Sankey diagrams can be produced using Python scripts or packages in R. The latter option requires specialized skills and is not a good alternative for Excel users. Though Sankey diagrams can be generated in Excel, it is a rather tedious procedure (Excel Hero 2010, Desktop Liberation n.d.). The following is an example of a Sankey diagram created in Excel.

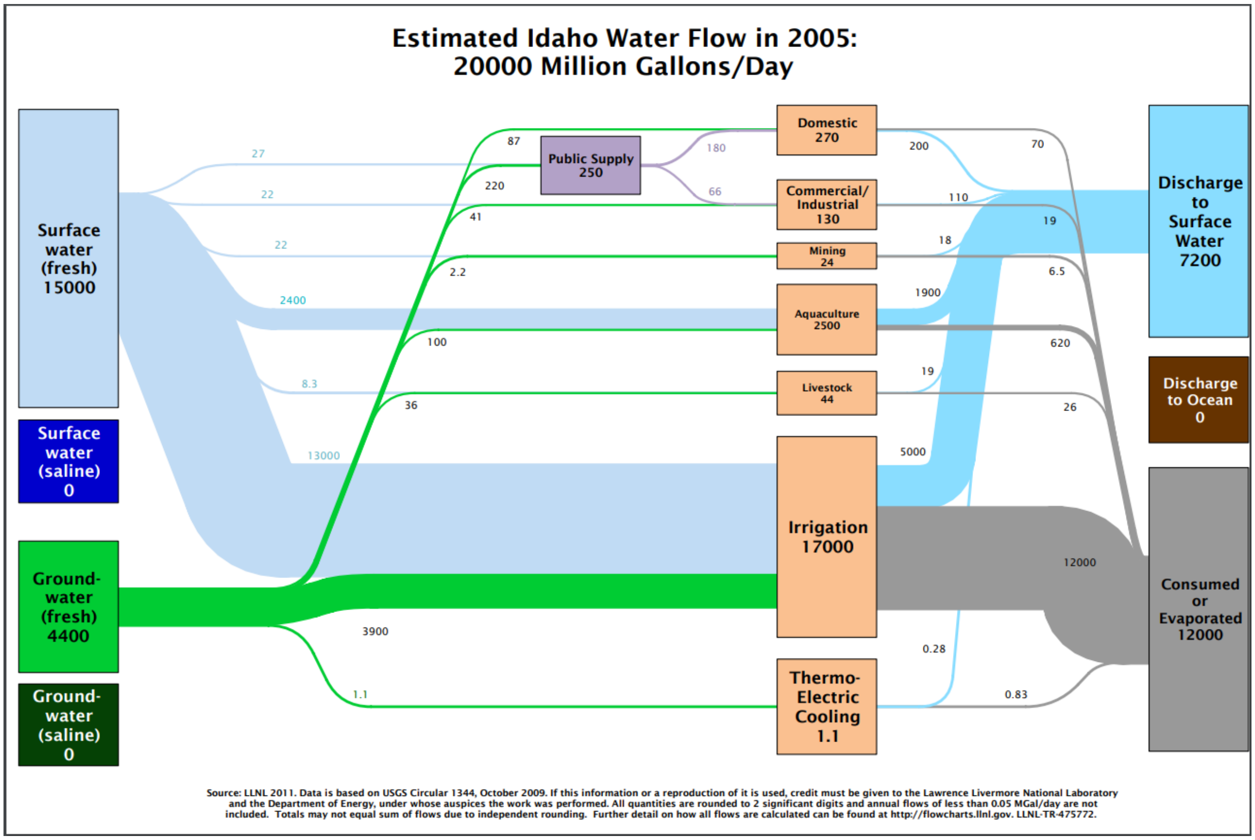


Figure 65. Example of Sankey diagram generated in Excel. Sourced from: excel hero blog, http://www.excelhero.com/blog/2010/03/energy-flow-chart.html, Attributed to: Estimated Water Flows in 2005: United States. Clara A. Smith, A.J. Simon, Rich Belles. Lawrence Livermore National Library. March 2011. https://flowcharts.llnl.gov/content/water/water_flow_archive/2005USStateWater.pdf

Adaptation and Mitigation

The purpose of the adaptation and mitigation section is to develop and compare a range of proposed actions that address supply and demand issues identified in the study. For the function conveying ***Comparison***, the following are examples of data graph types: ***Line Graph*** (Figure 65), ***Bar/Column Chart*** (Figures 66 and 67), and ***Pictograph Chart*** (Figure 69). Figure 68 includes the function conveying ***Composition*** in using the ***Pie Chart*** data graph type. Tables are also a common form of presenting adaptation and mitigation actions. As useful as they are in organizing and presenting facts and details it can be hard to visually draw comparisons. Figures 67 through 69 convert text and numbers into graphs and icons, using preattentive attributes to assist in pattern recognition and drawing comparisons.

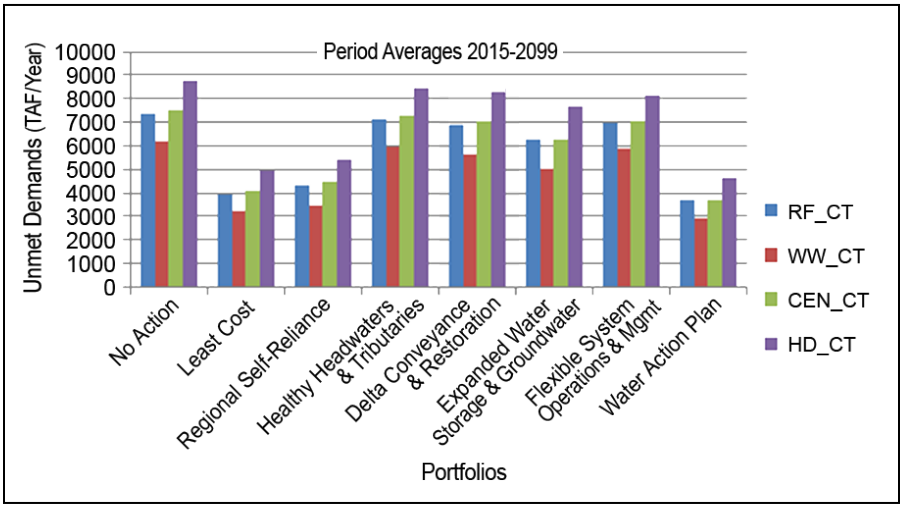


Figure 66. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), *Figure 7-1. Average annual unmet demands in the Central Valley in each adaptation portfolio.*

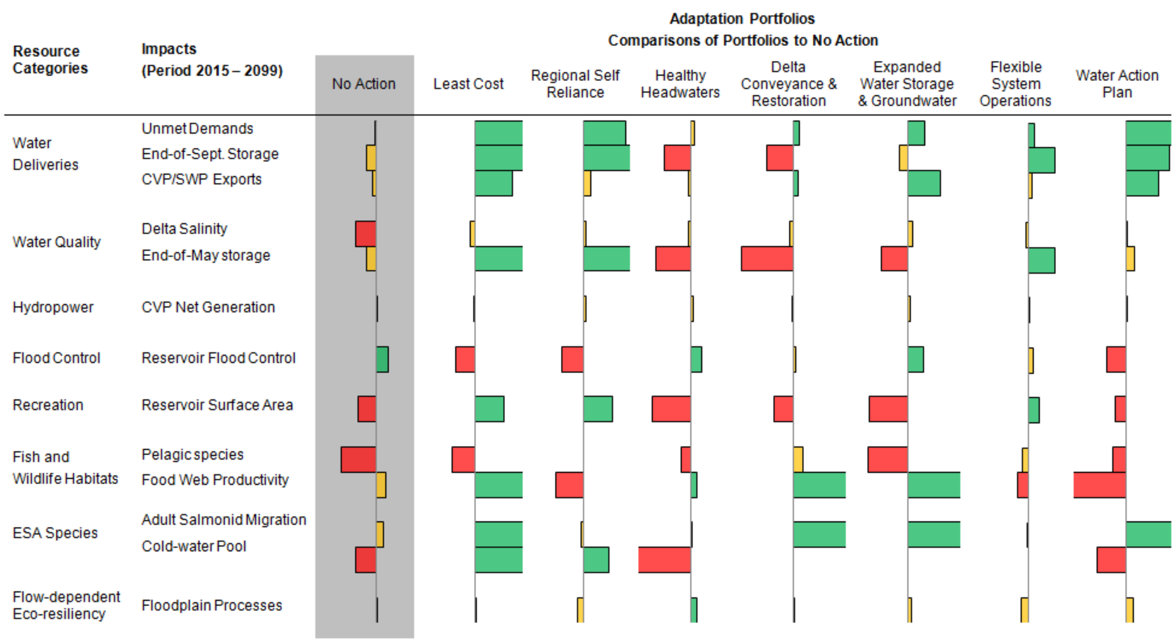


Figure 67. Example sourced from: Sacramento and San Joaquin Rivers Basin Study (Reclamation 2016e), *Figure 7-29. Summary Comparison of Adaptation Portfolios to the No Action Alternative.*

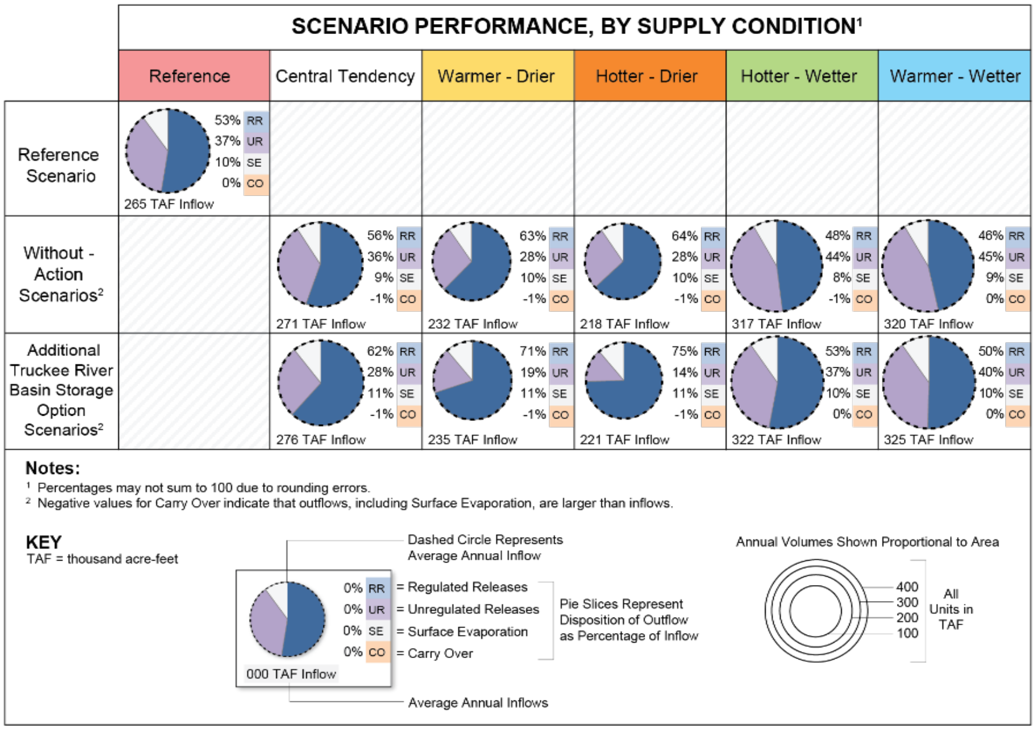


Figure 68. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), Figure 7-8. General operation in Truckee River basin reservoirs downstream from Lake Tahoe under Additional Truckee River Basin Storage Option

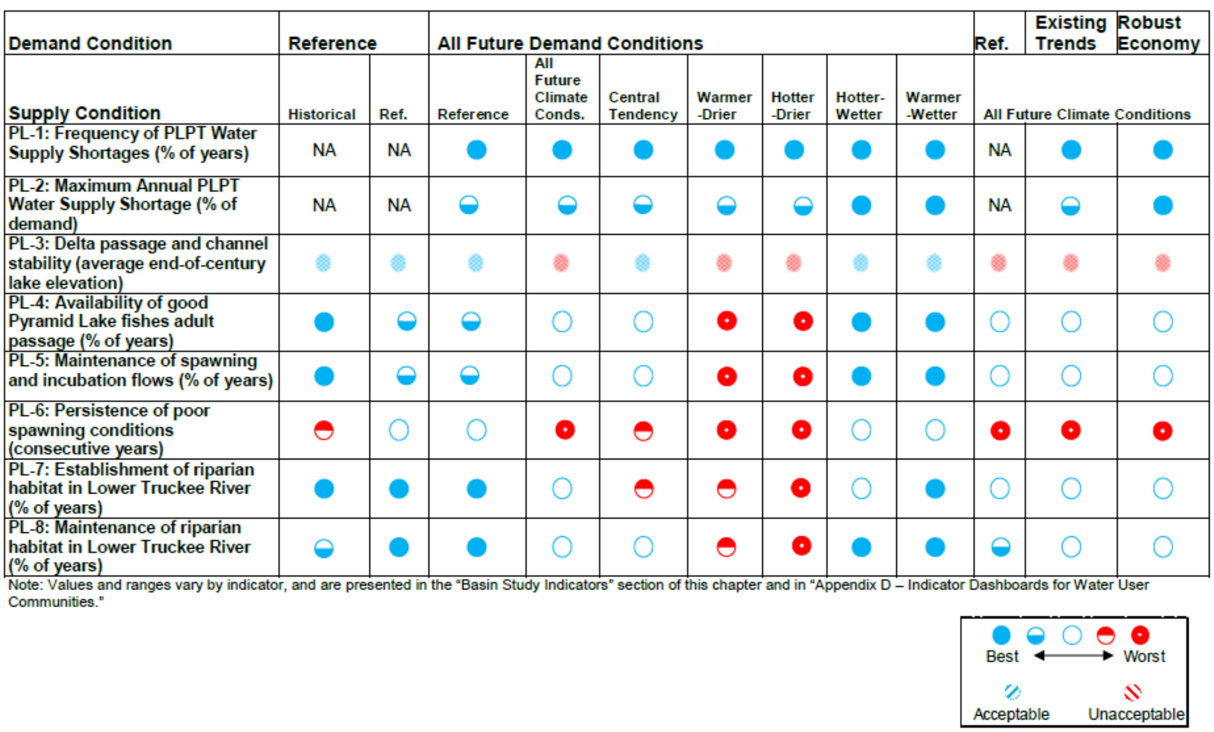


Figure 69. Example sourced from: Truckee Basin Study Report (Reclamation 2015d), ***Table 6-11. Pyramid Lake Indicator Values***

Adaptation and Mitigation – Redesign Considerations

Preattentive attributes, other than symbols and icons, can be included in data tables using conditional formatting to help in visually sorting and comparing values (Figure 70). The other option is to transform tables into a graphic. Six tables (Tables 3 through 8) from the economics technical report for the Republican River basin study (Reclamation 2015c) are combined into a conceptual table (Figure 71). Though the format does not adhere to any particular data graph type; it translates text into graphics and consolidates information to reduce memory demand and search efforts across multiple pages.

	A	B	C	D	E	F	G	H	I
1	Date	Location	Vanila	Strawberry	Temperature	Pamplets	Price	Total Sale	Total Revenue
2	1/1/2018	School	92	64	70	90	0.35	156	$54.60
3	1/2/2018	School	70	45	71	118	0.35	115	$40.25
4	1/3/2018	School	103	78	70	124	0.35	181	$63.35
5	1/4/2018	School	142	97	76	98	0.35	239	$83.65
6	1/5/2018	Mall	155	175	78	135	0.35	330	$115.50
7	1/6/2018	Mall	109	67	81	101	0.35	176	$61.60
8	1/7/2018	Station	102	93	83	95	0.35	195	$68.25
9	1/8/2018	Station	149	100	81	135	0.35	249	$87.15
10	1/9/2018	Station	129	95	82	113	0.35	224	$78.40
11	1/10/2018	Mall	144	151	85	126	0.35	295	$103.25
12	1/11/2018	Street	122	87	82	131	0.35	209	$73.15
13	1/12/2018	Street	169	109	83	135	0.35	278	$97.30
14	1/13/2018	Station	129	89	84	99	0.35	218	$76.30
15	1/14/2018	Station	107	77	79	109	0.35	184	$64.40
16	1/15/2018	Street	129	80	76	113	0.35	209	$73.15
17	1/16/2018	Mall	89	71	75	108	0.75	160	$120.00
18	1/17/2018	Mall	61	55	73	100	0.75	116	$87.00
19	1/18/2018	Mall	125	76	78	126	0.75	201	$150.75
20	1/19/2018	School	101	71	81	122	0.75	172	$129.00

Figure 70. Example of conditional formatting in Excel. Sourced from: edureka! blog, https://www.edureka.co/blog/data-visualization-using-excel/

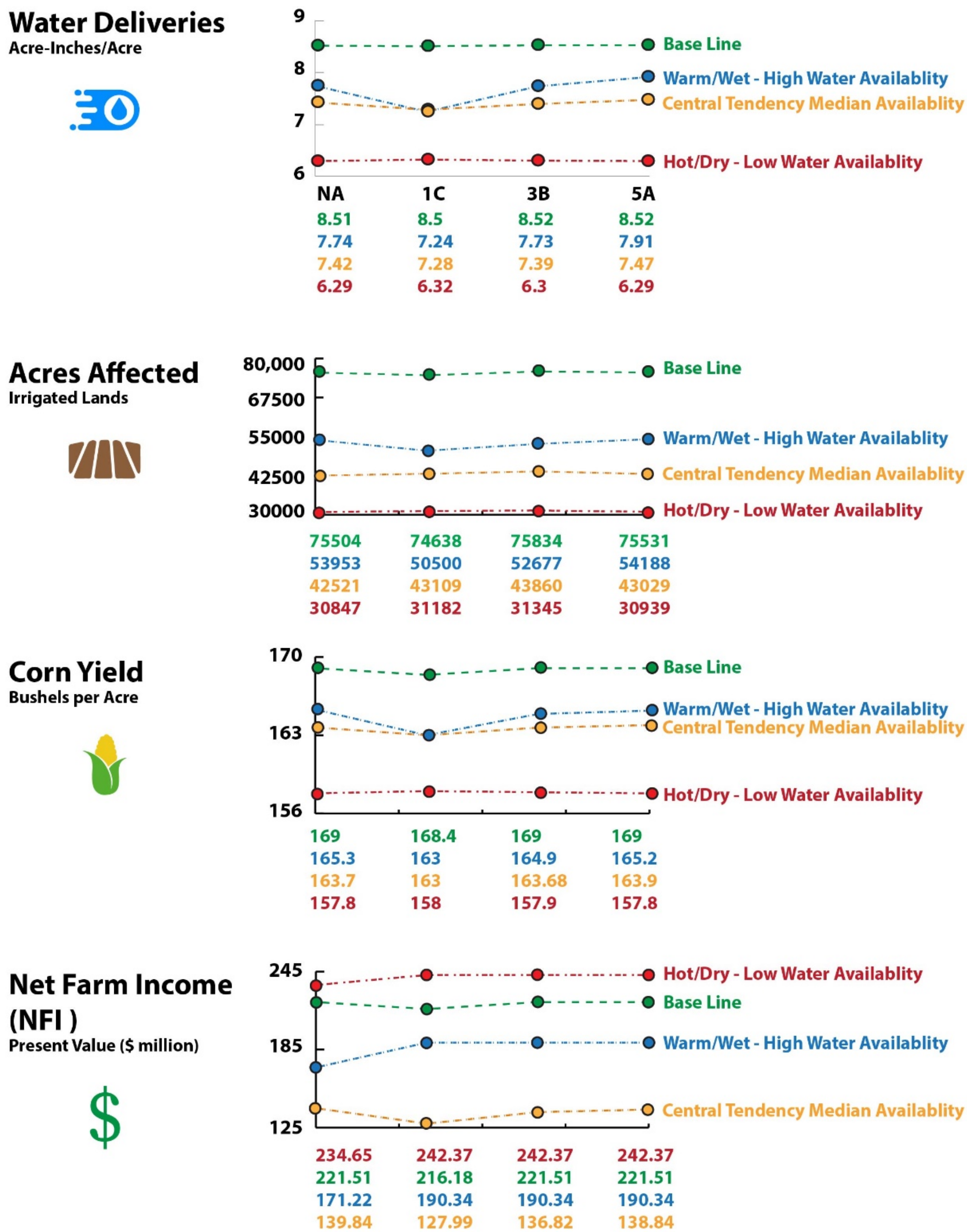


Figure 71. Example of transforming tables into data graphs: ***Agricultural Benefits Comparison of No Action versus Action Alternatives.***

Storytelling

A Reclamation study must adhere to a general template to document the science. Information products beyond the required template serve to *1) better explain historical and future change to physical systems; and 2) communicate Reclamation's response for adaptation and water resources management*. Coming full circle to the communication plan, effective communication is based on developing a narrative out of understanding what the audience should know about the study and what to do with the information. Data analysis drives data visualization in the study report. The narrative drives data visualization in information products tailored for an audience (The Presentation Company (n.d.)). The communication plan identifies a purpose and data visualizations are developed that expressly support that purpose; everything else that might be important in the study report is extraneous in this case.

The data visualization examples are presented in similar sequence as presented in a study report. The flow of information follows the sequence of a typical Reclamation analysis and the data graphs are designed to support the respective study section objectives. The following abbreviated outlines demonstrate this; how study analyses are reported step-by-step with a volume of text and data representations with emphasis on clearly reporting the results.

Sacramento and San Joaquin Rivers Basin Study (2016)
Chapter 3. Water Supply Assessment
    40 pages, 4 tables, 20 figures
Chapter 4. Water demand Assessment
    8 pages, 5 tables, 3 figures
Chapter 5. System Risk and Reliability Assessment
    106 pages, 21 tables, 18 figures
Chapter 6. Water Management Actions and Adaptation Portfolios
    34 pages, 11 tables, 2 figures
Chapter 7. Adaptation Portfolios Evaluation
    183 pages, 45 tables, 29 figures

WWCRA: Upper Rio Grande Impact Assessment (December 2013)
Chapter 2. Location and Background (surface water flow and groundwater)
    7 pages, of 9)
Chapter 3. Assessment Approach and Sources of Uncertainty (climate scenario description and stream flow simulations)
    7 pages, 2 figures
Chapter 4. Impact Assessment: Projected Climate and Water Supply
4.1 Climate in the Upper Rio Grande Basin: Past, Present, and Future
    8 pages
4.2 Impacts of Climate Change on Water Supply
    19 pages
4.3 Impacts of Climate Change on Water Delivery and Consumption
    29 pages, 2 tables, 37 figures

Chapter 5 Water Management Implications
 16 pages, 1 table, 7 figures
Chapter 6. Summary and Next Steps
 4 pages

Truckee Basin Study Report (2015)

Chapter 3. Water Supply Assessment
 56 pages, 8 tables, 38 figures
Chapter 4. Water Demand Assessment
 30 pages, 11 pages, 9 figures
Chapter 5. Water Management Conditions (infrastructure and operations)
 15 pages, 2 tables, 8 figures
Chapter 6. Risk and Reliability Assessment
 30 pages, 12 tables, 15 figures
Chapter 7. Responses to Risks
 45 pages, 16 tables, 15 figures
Chapter 8. Suggested Next Steps for Truckee Basin Communities
 9 pages, 1 table

Summary and Conclusion

The research question that initiated this study is broad and involves complexities of social sciences, visual perception and human cognition, and technical applications and artistic quality of data visualizations. This report suggests communication strategies that could be implemented and introduces data visualization guidance to accomplish effective communication. The purpose of the communications strategy recommendations that are presented is to 1) organize and solidify understanding of the overall substance of what is being studied, and 2) understand what information is relevant for target audiences. The emphasis should be on making information audience-accessible, not simply available. In other words, though technical reports are readily available, the format may hinder certain audiences from accessing the information they are interested in acquiring.

Many of the references we found regarding audience focused on audience segmentation. Audience segmentation is based in the social sciences, originated out of the business sector, and used towards targeted manipulation of consumer habits. Other sectors use it similarly to attempt to change public attitude towards sensitive subjects and issues. A draw-back to audience segmentation, or categorization in the casual sense, is reliance on remote and assumptive estimation of the audience’s interests and information needs. The best way to understand audience is through immediate contact and interaction.

The technical guidelines here provide a foundation in the creation and production of information products. There are other techniques, software tools, and "tips and tricks" that the report does not touch upon. Practitioners are encouraged to be adaptive, inquisitive, and creative as they work to advance effective communication within Reclamation. A more direct approach to advancing the work presented in this report is through dedicating workgroups to refine implementation of communication plans, establish a cadre of professional design specialists with the skills to produce advanced data visualizations, acquire software and tools to broaden design capabilities beyond current, standard options, and explore applications that can be used to produce interactive web-based data visualization services.

References

Abela, Andrew. 2006. “Choosing a Good Chart”, extremepresentation.typepad 6 Sept. 2006. http://extremepresentation.typepad.com/files/choosing-a-good-chart-09.pdf

Andrews, E.L. 2010. "National Academies Board on Science Education Workshop on Climate Change Education for the Public and Decision-Makers." December 17, 2010.

Beier, Paul, Lara J. Hansen, Lynn Helbrecht, and David Behar. 2016. A How-to Guide for Coproduction of Actionable Science. Conservation Letters 00(0), 1-9 https://doi.org/10.1111/conl.12300

Berinato, Scott. 2016. Visualizations That Really Work. Harvard Business Review. June 2016 Issue. https://hbr.org/2016/06/visualizations-that-really-work

Camoes, Jorge. November 4, 2013. A classification of chart type. http://excelcharts/com/classification-chart-types/

Center for Research on Environmental Decisions (CRED) and EcoAmerica. 2014. Connecting on Climate: A Guide to Effective Climate Change Communication. New York and Washington, D.C.

Desktop Liberation. (n.d.). Sankey diagrams from Excel. http://ramblings.mcpher.com/Home/excelquirks/d3/sankey

Excel Hero. 2010. Energy Flow Chart. March 8, 2010. http://www.excelhero.com/blog/2010/03/energy-flow-chart.html

Few, S. 2004a. Tapping the Power of Visual Perception. https://www.perceptualedge.com/articles/ie/visual_perception.pdf

Few, S. 2004b. Ennie, Meenie, Minie, Moe: Selecting the Right Graph for your Message. http://perceptualedge.com/articles/ie/the_right_graph.pdf

Few, S. 2016. The Visual Perception of Variation in Data Displays. https://www.perceptualedge.com/articles/visual_business_intelligence/the_visual_perception_of_variation.pdf

Healy, C.G.and J.T. Enns. 2012. Attention and Visual Memory in Visualization and Computer Graphics. IEEE Transactions on Visualization and Computer Graphics, Vol 18, No. 7, pp 1170-1188.

Institute for Natural Resources (INR). (n.d.) Willamette Water 2100. https://inr.oregonstate.edu/ww2100

Imhof, Eduard. 2007. Cartographic Relief Presentation. English-language edition edited by H. J. Steward. Walter de Gruyter, Genthiner Str. 13. D-10785 Berlin. Title of the original German-language edition: Kartographische Gelandedarstellung, Copyright © 1965 by

Walter de Gruyter & Co., Publishers, Berlin. Republished by ESRI Press, 380 New York Street, Redlands, California 92373-8100. First edition 2007. Copyright © 2007 ESRI.

Kahan, D. 2014. Making Climate-Science Communication Evidence Based—All the Way Down. In *Culture, Politics and Climate Change*, eds. M. Boykoff and D. Crow, pp. 203-21. (Routledge Press, 2014)

Larsen, D.E. 2015. Conveying Climate Change and Variability. https://www.usbr.gov/research/projects/researcher.cfm?id=884.

Locker, K. O. and S.K. Kaczmarek. 2006. Business Communication: Building Critical Skills, Sixth Edition. McGraw Hill Higher Education. ISBN:0-07-293210-4

Maibach, E., C. Roser-Renouf, and A. Leiserowitz. 2009. Global Warming's Six Americas 2009: An audience segmentation analysis. Yale Project on Climate Change and George Mason University Center for Climate Change Communication, New Haven, Connecticut, USA. Accessed 24 May 2010 at http://environment.yale.edu/uploads/6Americas2009.pdf.

Martinovic J, T. Gruber, and M.M. Müller. 2008. Coding of Visual Object Features and Feature Conjunctions in the Human Brain. PLos ONE 3(11):e3781. https://doi.org/10.1371/journal.pone.0003781

Medina, John. 2008. Brain Rules, 12 Principles for Thriving and at Work, Home, and School. Pear Press, Seattle, WA USA. ISBN-10:0-979777-0-4.

Moser, S.C. 2010. Communicating Climate Change: History, Challenges, Process and Future Directions. Wiley Interdisciplinary Reviews: Climate Change 1 (1), 31–53

Moser, S.C. and L. Dilling. 2011. Communicating Climate Change: Opportunites and Challenges for Closing the Science-Action Gap. In: *The Oxford Handbook of Climate Change and Society*, eds. Richard Norgaard, David Schlosberg, and John Dryzek, pp. 161-174. Oxford University Press Inc, New York, New York, USA. ISBN: 9780199566600

National Research Council (NRC). 2010. Informing an Effective Response to Climate Change. Washington, DC: The National Academies Press, 2010. doi:10.17226/12784.

National Science Board (NSB). 2014. Science and Engineering Indicators 2014. Arlington VA: National Science Foundation (NSB 14-01).

North Carolina State University (NCSU). 2016. *Audience Strategy*. Poole College of Management, North Caroline State University, Raleigh, North Carolina, USA. https://poole.ncsu.edu/pdfs/career_resources/Audience%20Strategy.pdf.

Patt, A. and S. Dessai. 2005. Communicating Uncertainty: Lessons Learned and Suggestion for Climate Change Assessment. Comptes Rendus Geoscience, Volume 337, Issue 4, Pages 425-441.

Plain Language Action and Information Network (PLAIN). 2011. Federal Plain Language Guidelines. PlainLanguage.gov. Revision 1, May 2011. https://plainlanguage.gov/media/FederalPLGuidelines.pdf

Public Law No. 96-511 (PL 96-511). 1980. An Act to reduce paperwork and enhance the economy and efficiency of the Government and the private sector by improving Federal information policymaking, and for other purposes. Enacted by the 96th United States Congress, December 11, 1980.

Reclamation. 2009. Biological Assessment on the Future Operation and Maintenance of the Rogue River Basin Project. Prepared by the U.S. Department of the Interior, Bureau of Reclamation, Columbia-Cascades Area Office, Yakima, Washington and Pacific Northwest Regional Office, Boise Idaho. October 2009. https://www.usbr.gov/pn/programs/esa/oregon/rogue2009/ba-rogue2009.pdf

Reclamation. 2011. Klamath River Basin Climate Change and Water Resources Assessment Plan of Study. Prepared by Reclamation, Mid-Pacific Region, Sacramento, California, California Department of Water Resources, and Oregon Water Resources Department.

Reclamation. 2013a. Biological Assessment for Bull Trout Critical Habitat in the Upper Snake River Basin. Prepared by Reclamation, Pacific Northwest Regional Office and Snake River Area Office, Boise Idaho. December 2013. https://www.usbr.gov/pn/programs/UpperSnake/2004ba/pdf/2013bulltroutba.pdf

Reclamation. 2013b. West-Wide Climate Risk Assessments: Upper Rio-Grande Impact Assessment. Prepared by the U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, Albuquerque, New Mexico. December 2013. https://www.usbr.gov/watersmart/baseline/docs/urgia/URGIAMainReport.pdf

Reclamation. 2015a. West-Wide Climate Risk Assessment: Irrigation Demand and Reservoir Evaporation Projections. Prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver Colorado. February 2015. https://www.usbr.gov/watersmart/baseline/docs/irrigationdemand/irrigationdemands.pdf

Reclamation. 2015b. Upper Deschutes River Basin Study. Prepared by Reclamation, Pacific Northwest Region, Boise, Idaho and Deschutes Basin Board of Control. April 2015. https://www.usbr.gov/pn/studies/deschutes/moa2015.pdf

Reclamation. 2015c. Economics Technical Report for the Republican River Basin Study. Technical Memorandum N. EC-2015-02. Prepared by: Technical Service Center, Water and Environmental Resources Division; Economics, Planning & Technical Communications Group. July 2015.

Reclamation. 2015d. Truckee Basin Study: Basin Study Report, Prepared by the U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region. Sacramento, California. December 2015. https://www.usbr.gov/watersmart/bsp/docs/finalreport/truckee/tbsbasinstudy.pdf

Reclamation. 2016a. West-Wide Climate Risk Assessment: Considerations for Selecting Climate Projections for Water Resources, Planning, and Environmental Analysis. February 2016.

Reclamation. 2016b. Knowledge Stream: Climate Variability and Extremes. U.S. Department of the Interior, Bureau of Reclamation, Research and Development Office. https://www.usbr.gov/research/docs/ks/ks-2016-03.pdf

Reclamation. 2016c. Missouri Headwaters Basin Study Plan of Study, Prepared by Reclamation, Montana Area Office, Billings, Montana and the State of Montana Department of Natural Resources and Conservation. October 2016. https://www.usbr.gov/gp/mtao/um_basin/plan_of_study.pdf

Reclamation. 2016d. Reclamation Manual Directives and Standards CMP 04-1. October 7, 2016, (minor revision).

Reclamation 2016e. Sacramento and San Joaquin Rivers Basin Study, Report to Congress 2015. Prepared for: U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region. Prepared by: CH2M Hill under Contract No. R12PD80946. March 2016. https://www.usbr.gov/watersmart/bsp/docs/finalreport/sacramento-sj/Sacramento_SanJoaquin_TechnicalReport.pdf

Reclamation 2016f. SECURE water Act Section 9503© 2016 Report to Congress, Chapter 2: Hydrology and Climate Assessment. Prepared for: United States Congress. Prepared by: U.S> Department of the Interior, Bureau of Reclamation, Policy and Administration, Denver, Colorado. https://www.usbr.gov/climate/secure/docs/2016secure/2016SECUREReport-chapter2.pdf

Ribeca, Severino (n.d.) The Data Visualization Catalogue. https://datavizxcatalog.com

Sankey, H.R. 1986. THE THERMAL EFFICIENCY OF STEAM-ENGINES. (INCLUDING APPENDIXES). In: Minutes of the Proceeding of the Institution of Civil Engineers, 125(1896), pp. 182–212. Published online: June 5, 2015 https://doi.org/10.1680/imotp.1896.19564

Schwabish, Jonathon, A. 2014. An Economist's Guide to Visualizing Data. Journal of Economic Perspectives, 28:1, pp 209-234.

Schwabish, Jonathon and Severino Ribecca. 2014. The Graphic Continuum. http://policyviz.com/graphic_continuum_inspiration/

SWD, Nussbaumer Knaflic, Cole. "tell your audience what you want them to know" *storytelling with data*, 13 May 2015, http://www.storytellingwithdata.com/blog/2015/05/tell-your-audience-what-you-want-them

SWD, Nussbaumer Knaflic, Cole. "declutter this graph" storytelling with data, 29 March 2107, http://www.storytellingwithdata.com/blog/2017/3/29/declutter-this-graph

SWD, Nussbaumer Knaflic, Cole. "putting graph elements in cells directly" *storytelling with data*, 15 June 2018, http://www.storytellingwithdata.com/blog/2018/6/15/putting-graph-elements-in-cells-directly

SWD, Nussbaumer Knaflic, Cole. "accessible data viz is better data viz" *storytelling with data*, 26 June 2018, http://www.storytellingwithdata.com/blog/2018/6/26/accessible-data-viz-is-better-data-viz

Tally, Jared L., Jen Schneider, and Eric Lindquist. 2016. A simplified approach to stakeholder agreement in natural resource management: the Five-Feature Framework. *Ecology and Society* 21(4):38. https://doi.org/10.5751/ES-08830-210438

The Presentation Company (n.d.). The Ultimate Guide: Data Visualization vs. Storytelling with Data. https://blog.presentation-company.com/data-visualization-vs.-data-storytelling-whats-the-difference

Thornton, Thomas L. and David L. Gilden. 2007. Parallel and Serial Processes in Visual Search. Psychological Review Vol. 114, No. 1, 71–103. DOI: 10.1037/0033-295X.114.1.71

Tufte, Edward R. 1990. Envisioning Information. Graphic Press, Cheshire, CT USA. ISBN-10: 0961392118.

Tufte, Edward R., 1997. Visual Explanations: Images and Quantities, Evidence and Narrative. Graphic Press, Cheshire, CT USA. ISBN-10: 1930824157.

Tufte, Edward R. 2001. The Visual Display of Quantitative Information (2nd ed.). Graphic Press, Cheshire, CT USA. ISBN-10:0-9613921-4-2

Tufte, Edward, R. 2006. Beautiful Evidence. Graphic Press, Cheshire, CT USA. ISBN-10: 1930824165

Tufte, Edward, R. (n.d.) The Work of Edward Tufte and Graphics Press. https://www.edwardtufte.com/tufte/q-and-a?topic_id=1

Ware, Colin. 2012. Information Visualization: Perception for Design (3rd ed.). Morgan Kaufman ISBN: 9780123814647

Weather Spark. 2016. The Typical Weather Anywhere on Earth. https://weatherspark.com/