TMDL Water Quality Study of the Virgin River Watershed

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1.0 INTRODUCTION

The entire Lower Colorado River watershed, including the Virgin River watershed, is located in Utah, Nevada, and Arizona (Figure 1-1). The principal drainage is the Virgin River and its tributaries: the East Fork Virgin River, North Fork Virgin River, North Creek, Ash Creek, La Verkin Creek, and the Santa Clara River. Beaver Dam Wash, Kanab Creek, Johnson Wash, and Seamans Wash provide additional drainage for the basin. The Virgin River drains into Arizona and ultimately the Colorado River.

Various segments of the Virgin River are listed on Utah's 2002 Section 303(d) list of impaired waters. The parameters responsible for the impairment are total dissolved solids, dissolved oxygen, temperature, and total phosphorus. The beneficial uses that are listed as impaired include cold water aquatic life (3A), other aquatic life (3C), and agriculture (4). Several of the listings are due to naturally high concentrations of TDS and therefore the adoption of site-specific criteria are being recommended as part of the Total Maximum Daily Load (TMDL) development process. Other listings (i.e., for high temperatures) were made in error and are being corrected. TMDLs are proposed in this document for the remaining waterbody/pollutant combinations.

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop TMDLs for waterbodies that are not meeting applicable water quality standards/guidelines or designated uses under technology-based controls. TMDLs specify the maximum amount of a pollutant which a waterbody can assimilate and still meet water quality standards. Based upon a calculation of the total load that can be assimilated, TMDLs allocate pollutant loads to sources and a margin of safety (MOS). This study determines allowable limits for pollutant loadings to meet water quality standards and designated uses for the Virgin River watershed. Pollutant load reductions are allocated among the significant sources and provide a scientific basis for restoring surface water quality. In this way, the TMDL process links the development and implementation of control actions to the attainment and maintenance of water quality standards and designated uses.

In Utah, the development of TMDLs is integrated within a larger watershed management framework that emphasizes a common-sense approach aimed at protecting and restoring water quality. Key elements of this approach include:

- Water quality monitoring and assessment
- Local stakeholder leadership
- Problem targeting and prioritization
- Integrated solutions that coordinate multiple agencies and interest groups.

The development of this TMDL has been conducted with these key elements in mind. The technical analysis has been based primarily on a wealth of water quality monitoring data collected by the Utah Division of Water Quality, the U.S. Geological Survey, and the Washington County Water Conservancy District. The Virgin River Watershed Management Plan Committee has been involved with the development of the TMDL and the recommendations of the TMDL will be integrated into the Committee's broader Watershed Management Plan. Other agencies that will be involved in identifying solutions in the watershed include the Natural Resources Conservation Service (NRCS), the U.S. Forest Service, the Bureau of Land Management (BLM), and the local municipalities and landowners.

The next sections of this document provide an overview of the applicable water quality standards (section 2) and potential pollutant sources (section 3). The remaining sections of the document discuss the technical approach used to identify existing and allowable loads (section 4); provide the results of the

TMDL allocations (section 5); and discuss implementation, monitoring and public participation activities (sections 6 to 8, respectively).

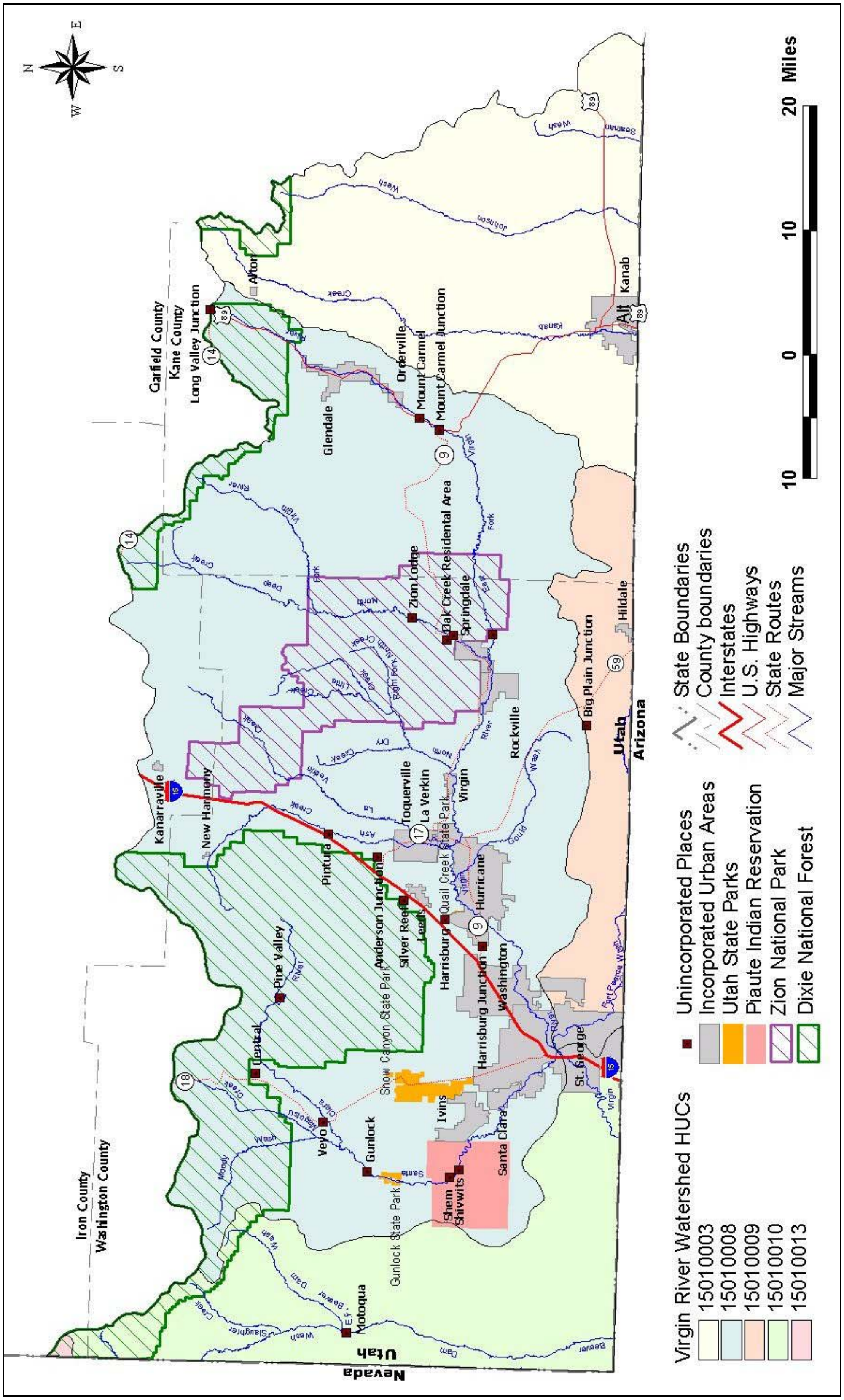

Figure 1-1. Location of the Lower Colorado River Watershed

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2.0 WATER QUALITY STANDARDS

Water quality standards are integral to the development of TMDLs because they provide the basis for measuring existing water quality and for identifying the extent to which conditions must be improved. This section presents the 303(d) listing status for the waters of concern, provides a description of each of the causes of impairment, and describes the applicable water quality standards.

2.1 303(d) List Status

Various segments of the Virgin River are listed on Utah's 2002 Section 303(d) list of impaired waters for total dissolved solids, dissolved oxygen, temperature, and total phosphorus, as shown in Table 2-1 and Figure 2-1 (UDEQ, 2002). The beneficial uses that are listed as impaired include cold-water aquatic life (3A), other aquatic life (3C), and agriculture (4).

Table 2-1. Information for the 2002 303(d) listed segments in the Lower Colorado River watershed.

Name	Impaired Beneficial Use(s)	Cause of Impairment	8-Digit HUC
Beaver Dam Wash (Motoqua to Headwaters)	3A	Temperature[1]	15010010
North Creek (confluence with Virgin River to headwaters)	4	Total Dissolved Solids	15010008
Santa Clara River (confluence with Virgin River to Gunlock Reservoir)	3C, 4	Total Dissolved Solids, Temperature, Selenium	15010008
Virgin River (State line to confluence with Santa Clara River)	4	Total Dissolved Solids	15010010
Virgin River and Tributaries (Santa Clara River confluence to La Verkin Creek, except Quail Creek to Leeds Creek)	4	Total Dissolved Solids	15010008
Kanab Creek and tributaries from Reservoir Canyon to headwaters	3A	Temperature[2]	15010003
Baker Dam Reservoir	3A	Total Phosphorus, Dissolved Oxygen, Temperature	15010008
Gunlock Reservoir	3A	Total Phosphorus, Dissolved Oxygen	15010008

[1] DWQ has changed the use designation of the Beaver Dam Wash from cold water aquatic life (3A) to warm water aquatic life (3B).
[2] DWQ is in the process of petitioning USEPA to have the temperature listings removed due to the fact the original listings were made in error.

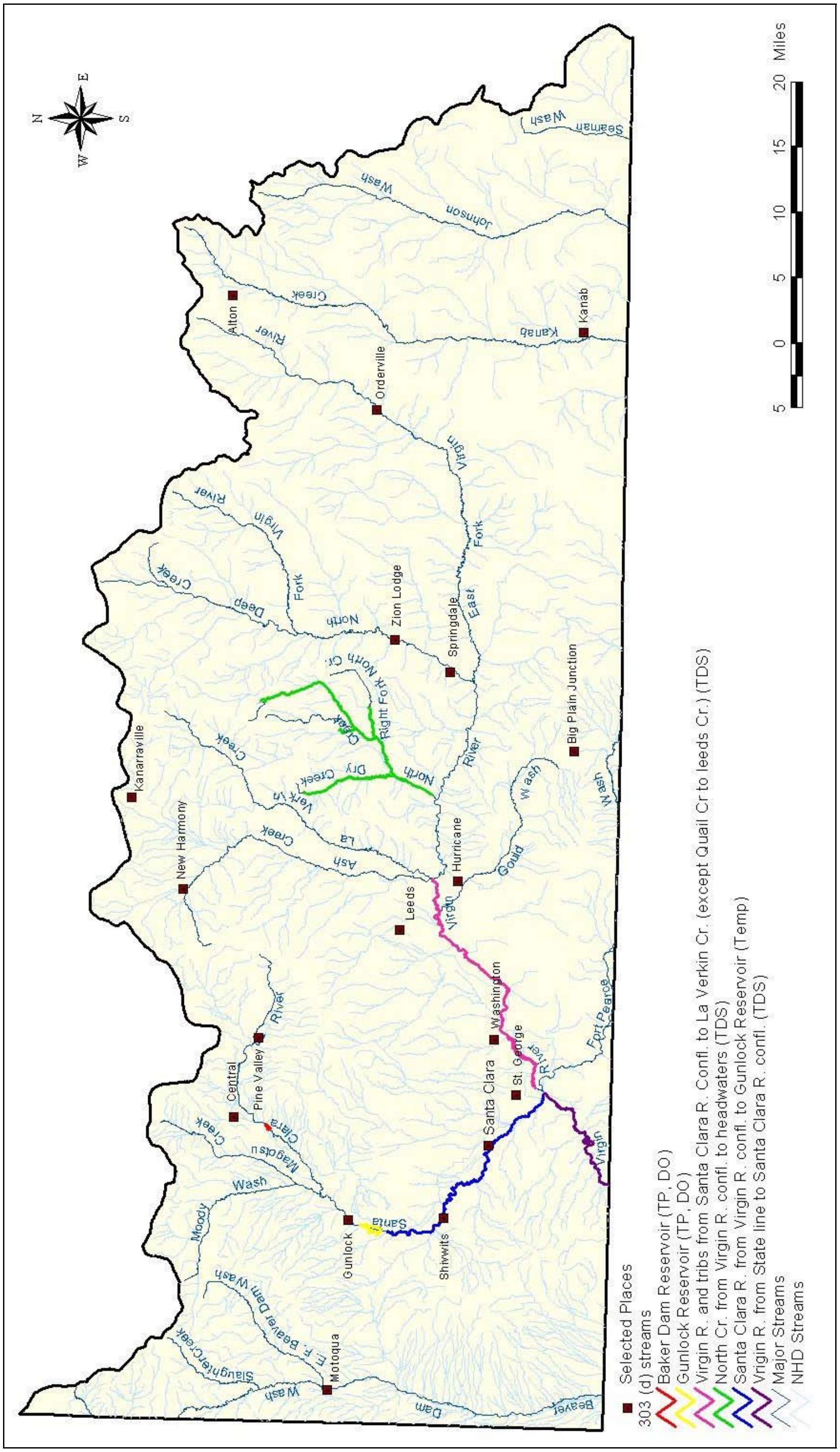

Figure 2-1. 303(d) list of impaired waters in the Lower Colorado River watershed.

2.2 Parameters of Concern

This section provides a summary of the parameters identified on the Utah 303(d) list as causing impairments in the Virgin River watershed. The purpose of the section is to provide an overview of the parameters, sampling methods, and potential sources for readers who might not be familiar with these issues. The relevance of the parameter to the various beneficial uses is also briefly discussed.

2.2.1 Salinity and Total Dissolved Solids

As water flows through a system, particles of soil, rock, and other materials accumulate in the water. The materials dissolve (or dissociate) in the water to form cations (positively charged ions) and anions (negatively charged ions). The term salinity refers to the total amount of dissolved cations and anions in water. Major ions in water are generally sodium, calcium, magnesium, potassium, chloride, sulfate, and bicarbonate. Metals (e.g., copper, lead, and zinc) and other trace elements (e.g., fluoride, boron, and arsenic) are usually only minor components of the total salinity. Salinity is determined by measuring the conductance of water, which is the opposite of resistance. This is done by sending an electrical current through the water and measuring the electrical conductance. The conductance of the water is corrected to a water temperature of 25 °C, and is called specific conductivity (SC). The units for SC are typically microsiemens per centimeter (µS/cm). SC is an easy and cost efficient measurement that can be performed in the field or the laboratory.

In addition to cations and anions, there are other dissolved substances in water, such as dissolved organic materials that are not measured by SC. The sum of all of the dissolved substances in water is called total dissolved solids (TDS), and is measured in milligrams per liter. TDS is a laboratory measurement and cannot be determined in the field. Pure distilled water has a TDS of zero. TDS concentrations in rainfall and snowfall vary, and generally range from zero to ten milligrams per liter. In comparison, the average TDS for the lower segment of the Virgin River near the Arizona border is 1,848 mg/L. Because dissolved organic materials are usually such a small percentage of TDS, SC and TDS typically measure the same amount of dissolved materials in water. However, the SC and TDS values of water cannot be directly compared because of the different sampling techniques and units (µS/cm versus mg/L).

The salinity of a waterbody is important to many aquatic organisms because it regulates the flow of water into and out of an organism's cells (osmosis). Increases or decreases in salinity can cause a shift in the composition of the natural aquatic community. In the Virgin River, it is likely that many native aquatic organisms have adapted to the natural moderate salinity. Uncharacteristically high salinity, however, can cause adverse effects on native vegetation such as willows and cottonwoods, and allow for the establishment of the invasive Tamarix, which is more tolerant of high salinity. Highly saline waters can adversely affect crop production depending on the amount of water applied and the salt tolerance of the crop. Livestock can also be adversely affected by high salinity values.

Natural sources, such as geology, soils, and geothermic activity, can contribute to the salinity of a stream. Watersheds that have easily erodible soils, or parent materials with high salt concentrations, have streams and lakes that have naturally high salinity. However, there are also several potential anthropogenic sources of salinity, such as agricultural irrigation returns, sand and gravel mining, disturbed land, road salting, and urban and agricultural runoff. Salinity can also be affected by flow alterations associated with irrigation diversions and reservoir management.

2.2.2 Temperature

Temperature impairment in a stream generally refers to a condition where some anthropogenic source, or a set of conditions caused by an anthropogenic source, has caused the natural temperature of a stream to increase to undesirable levels. Aquatic life beneficial uses can be impaired if the stream temperatures become too high because many species are not able to tolerate excessive instream temperatures. Agricultural uses of water are generally not affected by thermal modifications.

Potential sources of thermal modifications are industrial discharges and urban runoff. The removal of riparian cover (trees and shrubs) can also increase stream temperatures because of reduced shading. Additional factors that contribute to temperature impairments include shallow depths, low flows, and wider stream channels. In shallow, low flow streams, direct sunlight can increase water temperature more rapidly. Also, as stream channel width increases, the surface area of the stream increases which allows more sunlight to contact stream surfaces.

2.2.3 Total Phosphorus and Dissolved Oxygen

Phosphorus is necessary for aquatic life and is needed at some level in a waterbody to sustain life. The natural amount of phosphorus in a waterbody varies depending on the type of system. A pristine mountain spring might have little to almost no phosphorus, whereas a lowland, mature stream flowing through wetland areas might have naturally high concentrations. Various forms of phosphorus can exist at one time in a waterbody, although not all forms can be used by aquatic life. Common phosphorus sampling parameters are total phosphorus (TP), dissolved phosphorus, and orthophosphate.

Phosphorus generally does not pose a direct threat to the beneficial uses of a waterbody. However, excess phosphorus can cause an undesirable abundance of plant and algae growth. This process is called eutrophication or organic enrichment. One possible effect of eutrophication is low dissolved oxygen concentrations caused by respiration or the decay of excessive vegetation. Aquatic organisms need oxygen to live and they can experience lowered reproduction rates and mortality with lowered dissolved oxygen concentrations. Dissolved oxygen concentrations are measured in the field and are typically reported in milligrams per liter. Ammonia, which is toxic to fish at high concentrations, can be released from decaying organic matter when eutrophication occurs. Recreational uses can also be impaired. Nuisance plant and algae growth can interfere with swimming, boating, and fishing. Phosphorus generally does not pose a threat to agricultural uses.

Phosphorus exists in rocks and soils and is naturally weathered and transported into waterbodies. Organic matter is also a natural source of phosphorus. Systems rich with organic matter (e.g., wetlands and bogs) can have naturally high phosphorus concentrations. Phosphorus is also potentially released into the environment through different anthropogenic sources including septic systems, wastewater treatment plants, fertilizer application, and livestock operations.

2.2.4 Selenium

Selenium is an essential trace nutrient for various aquatic organisms. However, in elevated concentrations selenium has been proven to cause mortality, deformity, and reproductive failure in fish and aquatic birds (USEPA, 1998). The toxicity of selenium depends on the form. In alkaline soils and in oxidizing conditions selenium uptake is increased because it is in its biologically active form, which increases its availability to aquatic organisms.

Selenium is found throughout the West in marine Cretaceous shale deposits. Selenium occurs in sulfide ores of heavy metals including pyrite, clausthalite, naumannite, tienammite, and seleosulfur. In addition, soils in proximity to volcanic activity contain elevated selenium concentrations. Selenium is also an enriched element in coal. Irrigation practices have been noted to concentrate selenium when irrigation waters evaporate and concentrate the dissolved components (GBSTF, 2003). Anthropogenic sources of selenium include the combustion of coal and petroleum fuels and the smelting or other metals.

2.3 Applicable Water Quality Standards

Under the Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters. These standards represent a level of water quality that will support the Clean Water Act's goal of "swimmable/fishable" waters. Water quality standards consist of three different components:

- **Beneficial uses** reflect how humans can potentially use the water and how well it supports a biological community. Examples of beneficial uses include aquatic life support, drinking water supply, and recreation. Every water in Utah has a designated use or uses; however, not all uses apply to all waters.
- Criteria express the condition of the water that is necessary to support the beneficial uses. **Numeric criteria** represent the concentration of a pollutant that can be in the water and still protect the beneficial use of the waterbody. **Narrative criteria** are the general water quality criteria that state that all waters must be free from sludge; floating debris; oil and scum; color- and odor-producing materials; substances that are harmful to human, animal or aquatic life; and nutrients in concentrations that may cause algal blooms
- The **antidegradation policy** establishes situations under which the state may allow new or increased discharges of pollutants, and requires those seeking to discharge additional pollutants to demonstrate an important social or economic need.

The Utah Water Quality Board (UWQB) is responsible for creating the water quality standards that are then enforced by the Utah Department of Environmental Quality, Division of Water Quality (DWQ). Utah has numeric criteria for TDS, dissolved oxygen, selenium, and temperature and a pollution indicator value for TP. These standards are found in the Utah Administrative Code, Standards of Quality for Waters of the State R317-2 and vary based on the beneficial use assignment of the waterbody. Table 2-2 summarizes the standards pertaining to the 303(d) listed segments in the Lower Colorado River watershed.

Table 2-2. Water quality standards for impaired waters in the Lower Colorado River watershed.

Designated Use	Description	TDS	Temperature	Dissolved Oxygen[1]	Selenium	TP Pollution Indicator
3A	Cold water aquatic life	—	Max.: 20 ºC Max. change: 2 ºC	30 day avg: 6.5 7 day avg: 9.5/5.0 1 day avg: 8.0/4.0	4 day avg: 4.60(µg/L) 1 hour avg: 20 (µg/L)	0.025 mg/L (max) for lakes
3B	Warm water aquatic life	—	Max.: 27 ºC Max. change: 4 ºC	30 day avg: 5.5 7 day avg: 6.0/4.0 1 day avg: 5.0/3.0	4 day avg: 4.60 (µg/L) 1 hour avg: 20 (µg/L)	0.025 mg/L (max) for lakes
3C	Other aquatic life	—	Max.: 27 ºC Max. change: 4 ºC	30-day avg: 5.0 1 day avg: 3.0	4 day avg: 4.60 (µg/L) 1 hour avg: 20 (µg/L)	
4	Agricultural use	1200 mg/L (max)			0.05 mg/L (Max)	—

[1]These limits are not applicable to lower water levels in deep impoundments. First number in column is for when early life stages are present, second number is for when all other life stages are present.

The beneficial use support status for streams in Utah is determined using the water quality standards shown in Table 2-2. Utah has determined guidelines for assessing each beneficial use. The guidelines for assessing class 3 aquatic life uses are shown in Table 2-3 and the guidelines for assessing class 4 agricultural uses are shown in Table 2-4 (UDEQ, 2002).

Table 2-3. Criteria for assessing aquatic life beneficial use support classes 3A, 3B, and 3C.

Degree of Use Support	Classification Criteria
Full	For any one pollutant, no more than one exceedance of criterion or criterion was not exceeded in < 10% of the samples if there were 2 or more exceedances
Partial	For any one pollutant, criterion was exceeded 2 times, and criterion was exceeded in more than 10% of the samples but not more than 25% of the samples
Non	For any one pollutant, criterion was exceeded 2 times, and criterion was exceeded in more than 25% of the samples

Table 2-4. Criteria for assessing agricultural beneficial use support class 4 for total dissolved solids.

Degree of Use Support	Classification Criteria
Full	Criterion was exceeded in less than 2 samples and in <10% of the samples if there were 2 or more exceedances
Partial	Criterion was exceeded 2 times, and criterion was exceeded in more than 10% but not more than 25% of the samples
Non	Criterion was exceeded 2 times, and criterion was exceeded in more than 25% of the samples

DWQ uses the following additional procedures to evaluate Class 3 (aquatic life) beneficial use in lakes and reservoirs:

1. Three basic parameters that are compared to standards in addition to other specific parameters include dissolved oxygen, pH, and temperature. These basic parameters are obtained in the field as part of the overall monitoring program for Utah's lakes and reservoirs. The data for these three parameters are analyzed for the entire water column and evaluated according to 305(b) guidelines. A comparison of water column values with water quality standards is determined as follows. For any one pollutant or stressor, criteria exceeded in less than or equal to 10 percent of measurements, a designation of fully supporting is assigned. For any one pollutant or stressor, criteria exceeded in greater than 10, but less than or equal to 25 percent of measurements, a designation of partially supporting was assigned. For any one pollutant or stressor, criteria exceeded in greater than 25 percent of measurements a designation of not supporting was assigned. An exception to these guidelines has been provided for dissolved oxygen. Exceedance criteria for dissolved oxygen have been defined using the 1-day minimum dissolved oxygen concentration of 4.0 mg/l. State standards account for the fact that anoxic or low dissolved oxygen conditions may exist in the bottom of deep reservoirs and therefore, the dissolved oxygen standard is applied as follows. When the concentration is above 4.0 mg/l for greater than 50 percent of the water column depth, a fully supporting status is assigned. When 25 to 50 percent of the water column is above 4.0 mg/l, it is designated as partial supporting and when less than 25 percent of the water column exceeds the 4.0 mg/l criteria; it is designated as not supporting its defined beneficial use. Having determined support status for individual pollutants or stressors, an overall use designation is determined based on a combination of the individual pollutant or stressor support designations. A ‘not supportive’ status was assigned to a body of water when at least two of the basic criteria (dissolved oxygen, pH or temperature) were found to be not supportive. A ‘fully supporting’ status was assigned when all of the criteria were found to be fully supporting. All other waterbodies were assigned a 'partially supporting' status for criteria found in the various remaining combinations.

2. The initial support status may be modified through an evaluation of the trophic state index (TSI), winter dissolved oxygen conditions with reported fish kills, and the presence of significant blue green algal populations in the phytoplankton community. This evaluation, although based to an extent on professional judgment, could shift initial support status ranking downward if two of the three criteria indicate there is an impairment in the water quality.

3. A final determination to list the waterbody is made through an evaluation of assessment trends since 1989. It is necessary to incorporate such an evaluation to incorporate the hydrology and seasonality associated with lakes and reservoirs. In general, if a waterbody exhibits a consistent status of ‘partial supporting’ or ‘not supporting’, it should be listed on the 303(d) list. However, some waterbodies appear to be borderline and exhibit a mixture of partially and fully supporting conditions over the period of study. Therefore, a minimum of two consecutive evaluation cycles, in any particular support status, are required for addition to or removal from the 303(d) list.

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3.0 SOURCE ASSESSMENT

Field assessments of the Virgin River watershed were conducted during the weeks of October 7, 2002 and June 7, 2003 to obtain a better understanding of water quality issues and the potential sources of pollution in the watershed. The assessments were performed for the majority of the Virgin River watershed through on-the-ground surveys complemented with an aerial reconnaissance and photo analysis. During the on-the-ground surveys potential sources of pollution were identified and located using a GARMIN 3+ global positioning system (GPS) with up to five-foot accuracy. These sources included animal feeding operations (AFOs), wastewater lagoons, industrial sources, areas of disturbance, streambank erosion, agricultural practices, agricultural return flows, sand and gravel operations, and natural sources. Potential opportunities for implementation were also identified during the field assessments. Table 3-1 summarizes the potential sources for each cause of impairment in the Virgin River watershed and the following sections describe the conditions of various potential sources of pollution in the Virgin River watershed. Section 4 explains how pollutant loads were estimated from each of these source categories and section 5 provides detailed source loading estimates for each stream segment.

Table 3-1. Summary of sources of impairment in the Lower Colorado River watershed.

Name	Parameter	Sources
Kanab Creek and tributaries from Reservoir Canyon to Leeds Creek	Temperature	Natural conditions
North Creek (confluence with Virgin River to headwaters)	TDS	Natural erosion; limited agricultural impacts
Virgin River (State line to confluence with Santa Clara River)	TDS	Streambank erosion/land erosion, upstream, Fort Pearce Wash, St. George WWTP, Santa Clara River, urban dryweather and stormwater, irrigation return flows, geothermal, geology
Virgin River and Tributaries (Santa Clara River confluence to La Verkin Creek, except Quail Creek to Leeds Creek)	TDS	Pah Tempe Hot Springs, land erosion, geothermal
Baker Dam Reservoir	Total Phosphorus	Septic systems, livestock, land erosion/streambank erosion
	DO	Septic systems, livestock, land erosion/streambank erosion
	Temperature	Natural conditions, reservoir management
Gunlock Reservoir	Total Phosphorus	Land erosion/streambank erosion, livestock, internal loading, septic systems
	DO	Land erosion/streambank erosion, livestock, internal loading, septic systems
Santa Clara River (confluence with Virgin River to Gunlock Reservoir)	TDS	Streambank erosion/land erosion, upstream, stormwater/dryweather flows, irrigation return flows.
	Temperature	Natural conditions
	Selenium	Streambank/hillslope erosion, irrigation return flows, stormwater/dryweather flows from Phase II communities.
Beaver Dam Wash (Motoqua to headwaters)	Temperature	Natural conditions

3.1 Geology

The Lower Colorado River watershed contains a variety of geologic formations consisting of sedimentary and igneous rocks as well as a number of fault zones. Sandstone is the predominant sedimentary rock in the watershed but significant quantities of limestone, shale, and some gypsum are present. Storm runoff through these loose sedimentary rocks can deliver a high amount of sediment to streams. Additionally, faulting along the Hurricane Ridge influences water quality by providing a conduit for upward flow of saline water at the Pah Tempe (or La Verkin) hot springs.

Soil erodibility can be assessed using the Natural Resource Conservation Service's (NRCS) STATSGO soils database. A commonly used soil attribute is the K-factor, a component of the Universal Soil Loss Equation (USLE). The K-factor is a dimensionless measure of a soil's natural susceptibility to erosion, and factor values may range from 0 for water surfaces to 1.00 (although, in practice, maximum factor values do not generally exceed 0.67). Large K-factor values reflect greater inherent soil erodibility. The distribution of K-factor values in the Lower Colorado River basin is shown in Figure 3-1. The figure indicates that soils with moderate erosion potential (e.g. K-factors ranging from 0.20 to 0.37) are widely distributed throughout the watershed, and comprise approximately 67 percent of the soils in the basin. Low and low-to-moderate K-factor values share equal proportions of the watershed (16 percent).

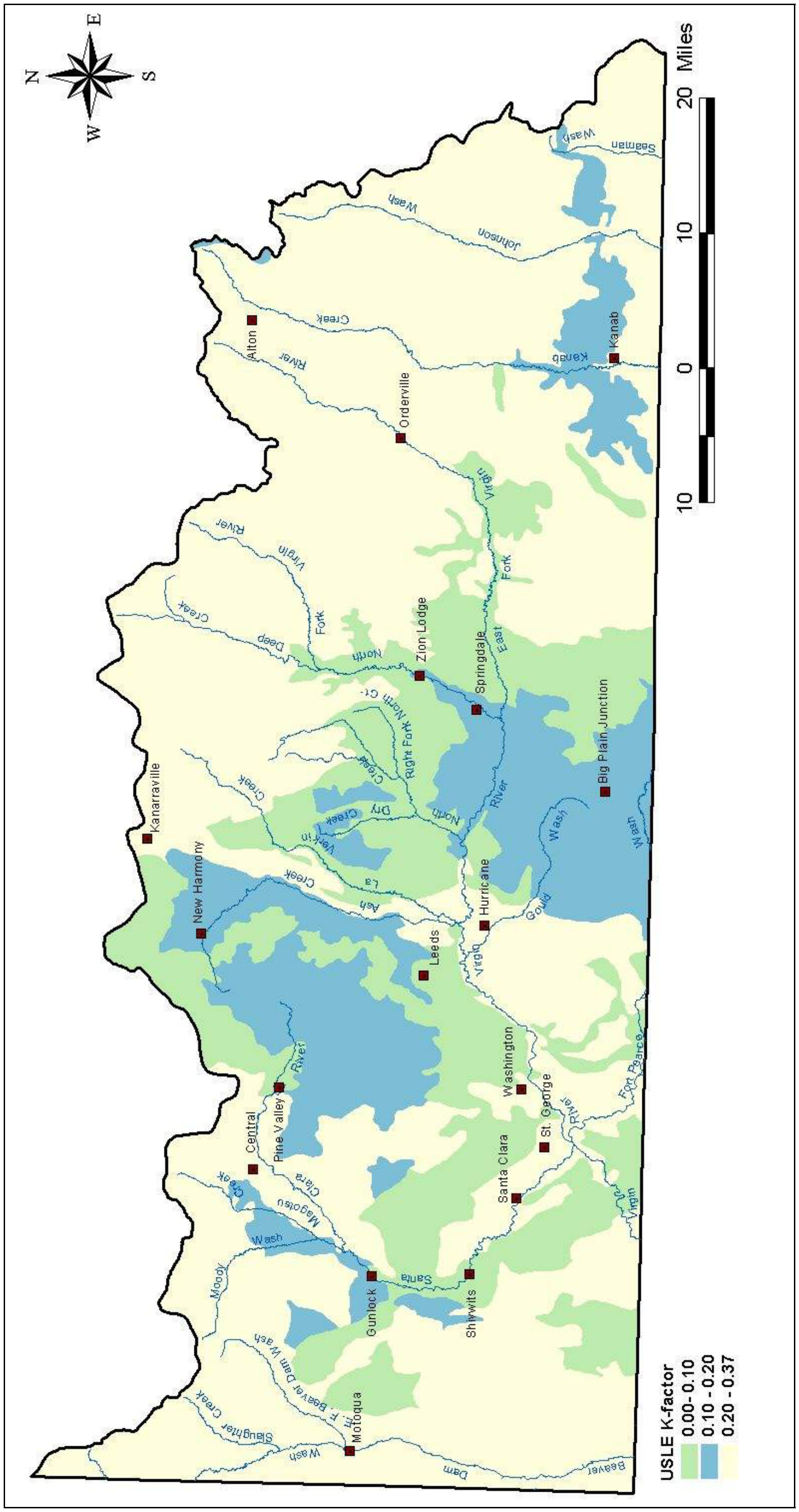


Figure 3-1. USLE K-factors in the Lower Colorado River watershed.

Certain soils in the Virgin River watershed are highly erosive in nature with naturally high salinity.

Salts are naturally occurring in the Virgin River watershed due to bedrock materials that are easily weathered. These salts are found in varying concentrations in soils and waters throughout the basin. In arid regions, salts accumulate in soils due to evaporation, which concentrates salts in the upper soil layers. NRCS classifies saline as having an electrical conductivity greater than 4,000 μS/m.

Figure 3-2 shows the distribution of soil salt concentrations in the watershed. Data were obtained from the STATSGO database and represent a weighted sum of the maximum salinity reported for all soil series in the surface layer of a map unit. It should be noted that map units can be highly variable and Figure 3-2 is meant as a general representation of salinity throughout the watershed. Additionally, it is important to note that the STATSGO database did not contain maximum salinity values for the headwater portions of the Santa Clara River, Ash Creek, North Fork Virgin River, North Creek, and the Kanab Creek drainages. Most of the soils in the watershed had maximum electrical conductivities between 500 μS/m and 2,000 μS/m. The highest reported electrical conductivities are found on the Virgin River from the Santa Clara River confluence upstream to the Ash Creek confluence and also in the lower reaches of Fort Pierce Wash. The area of lowest salinity was reported for the headwaters of the North Fork Virgin River.

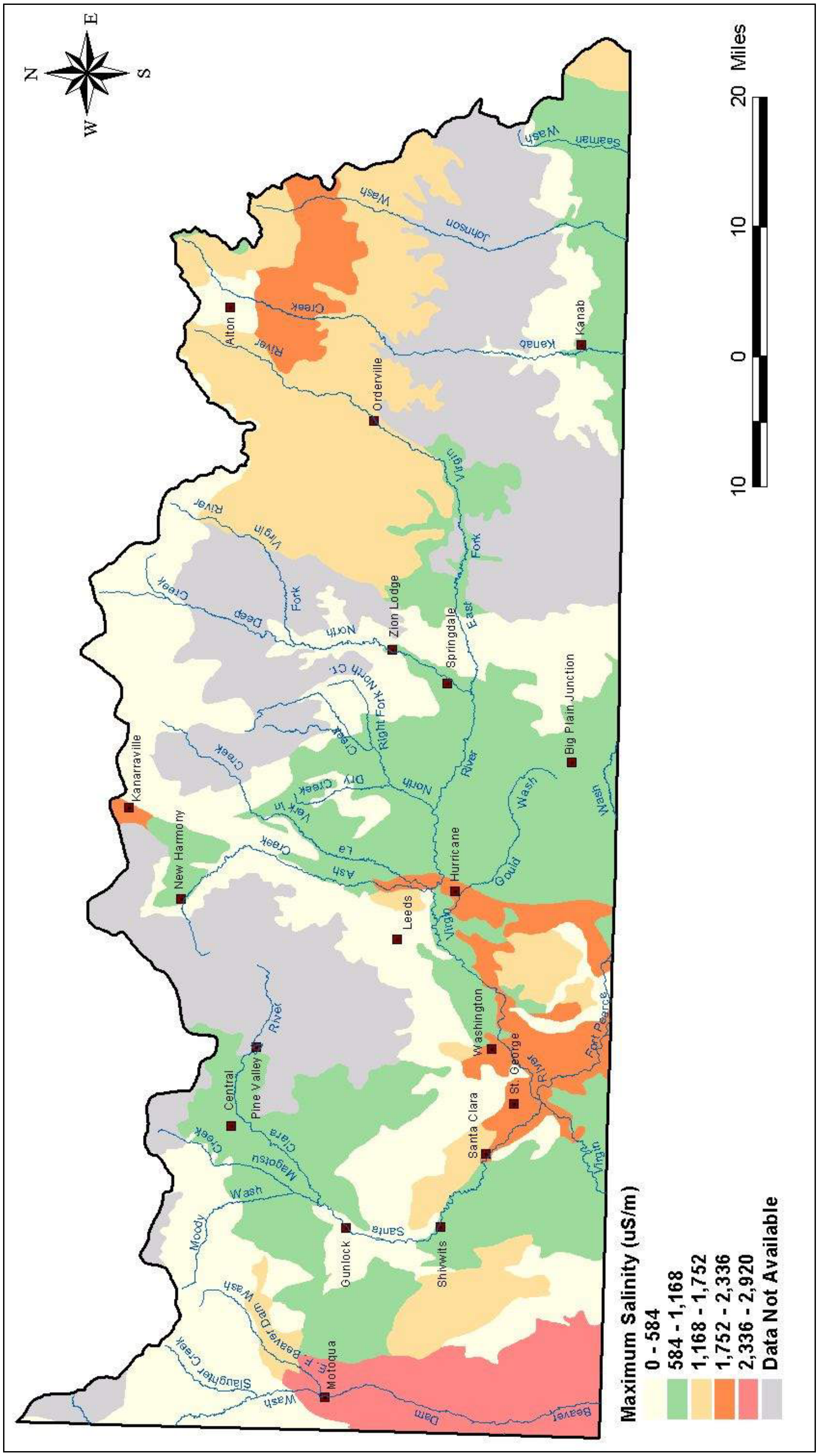
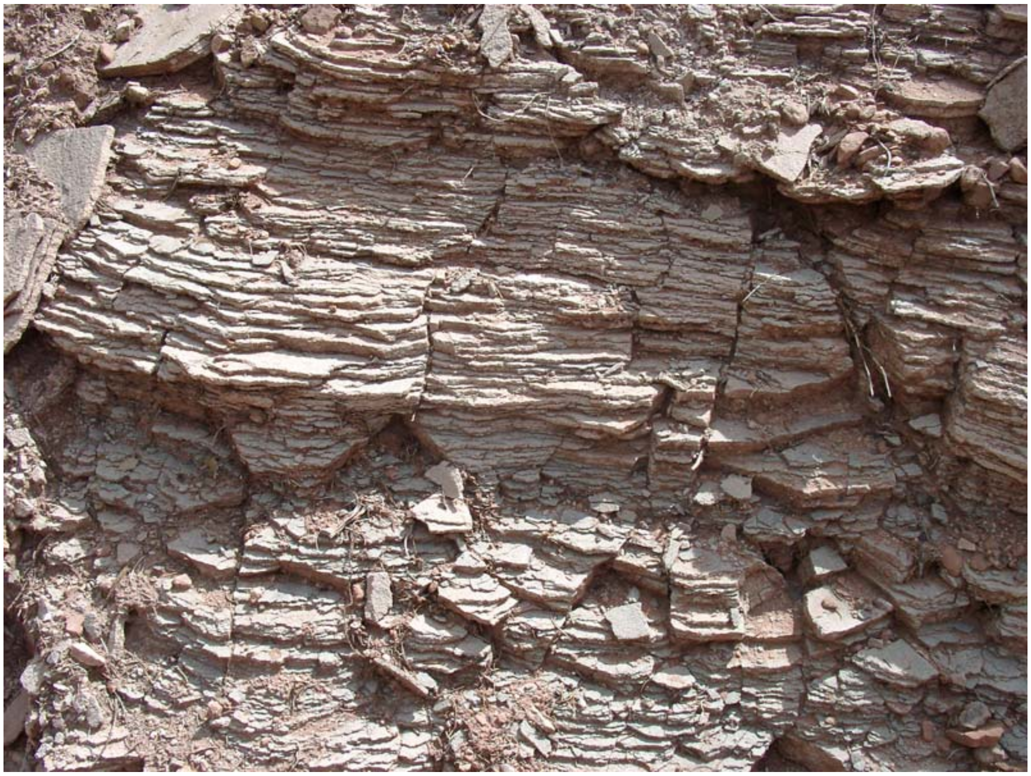


Figure 3-2. Distribution of maximum salinity content.



Saline shale formations, like these from Dry Creek, are highly erosive and can contribute large amounts of stream salinity.

Geologic formations in the watershed naturally dissolve and contribute salts.

3.2 Geothermal Activity

Geothermal activity can greatly affect water chemistry. Hot springs, geysers, and other geothermal activity can contribute dissolved solids, along with multiple other chemical constituents that affect water chemistry. Several hot springs exist within the Virgin River watershed, including the largest, the Pah Tempe (or La Verkin) hot springs, which discharge directly to the Virgin River. The effect of these hot springs on water quality is discussed in more detail in section 5.

The Pah Tempe hot springs contribute large amounts of water naturally high in TDS directly to the Virgin River near Hurricane.

3.3 Animal Feeding Operations

Several animal feeding operations (AFOs) are present in the Virgin River watershed, primarily located in the Washington Fields area east of St. George. However, this area is experiencing tremendous population growth and much of the agricultural land is being replaced with residential development. The few large AFOs that remain have the potential to affect stream water quality because the cattle are sometimes present within the irrigation diversion channels, allowing for direct discharge of nutrients to the Virgin River or its tributaries. Additional poor management practices that were observed included overgrazing and poor manure management.

Animal feeding operation along irrigation diversion in Washington Fields.

3.4 Irrigation

The Virgin River and many of the other major tributaries in the watershed are diverted several times for domestic and agricultural uses. More than 50 percent of the diversions are used for irrigation and stockwatering. Irrigation practices in the watershed are a potential source of salinity and nutrients because irrigation water can acquire nutrients and salinity from fields and return them to surface waters through return flows and groundwater. Flood irrigation in particular is a potential source of salinity because of the large amounts of water used in the process and the need to leach salts from agricultural fields.

Irrigation diversion in the Washington Fields area near St. George.

During the field assessment, it was noted that almost all of the agricultural fields in the Virgin River watershed were irrigated by some method. Most fields were irrigated with flood irrigation through the use of canals. Return flows were mostly through subsurface flow, or tiled drainages, and several of these returns were observed to be entering active stream channels. Other types of irrigation in the watershed included center pivot and side-roll irrigation sprinkler systems.

As fields are flood irrigated, water evaporates concentrating and leaving behind salt crusts as seen here in the Washington Fields area near St. George.

3.5 Streambank Erosion

A general streambank erosion assessment was performed throughout the Lower Colorado River watershed by documenting the extent of streambank erosion and entrenchment. Streambank erosion is a potential source of sediment and TDS for streams in the watershed. The different types of streambank erosion observed in the watershed are listed below.

- Entrenchment
- General disturbance (i.e., cattle grazing on stream-banks)
- Channelization
- Flow alterations (i.e., below the dams)
- Lateral incision

In general, the Virgin River main stem is fairly stable in most locations. However, many of its tributaries have substantial stream erosion, with the worst occurrences being noted in the East Fork of the Virgin River and Muddy Creek. There is only one area on the main stem of the Santa Clara River, just upstream of Gunlock Reservoir, where streambank erosion is severe.

Streambank erosion can be natural but can also be exacerbated by poor management practices as seen in this culvert design in the Dry Creek subwatershed.

Streambank erosion on Muddy Creek near Orderville.

Erosion on the Santa Clara River just upstream of Gunlock Reservoir.

3.6 Wastewater Disposal

There are several wastewater lagoons located adjacent to the Virgin River or one of its tributaries that could contribute to TDS and TP loadings through seepage. Septic systems are also potential sources of TP when they are located on inadequate soils, are densely packed together, and are located near a surface water.

The Rockville wastewater lagoons are adjacent to the river but no leakage was observed during the field visits. The Hurricane - La Verkin - Toquerville lagoons are located adjacent to the Virgin River and were suspected to be leaking into the stream course through subsurface flows. However, recent documentation supplied by the Ash Creek Special Services District indicates that the observed flows predated the lagoons, and are likely caused by groundwater outfalls and flows. Therefore the Hurricane – La Verkin – Toquerville wastewater lagoons are not viewed as a source of pollutant loadings. The Orderville wastewater lagoons are located near the East Fork of the Virgin River and no leakage was observed during the field visits. The St. George wastewater treatment plant is located along the Virgin River near the confluence with the Santa Clara River. The plant employs tertiary treatment including disinfection through the use of ultraviolet light. Effluent from the plant was observed to be very high quality during the field surveys.

Aerial view of the Hurricane lagoons located next to the Virgin River.

Aerial view of the St. George wastewater treatment plant.

Treatment of domestic waste in Pine Valley is primarily by septic systems, and is located in a wet alpine meadow area in the headwaters of the Santa Clara River.

Septic systems in the Pine Valley area could be contributing TP to the Santa Clara River, and eventually to Baker and Gunlock Reservoirs. Pine Valley is located in a large wet meadow and subsequently the septic systems are not high above the groundwater levels. This increases the possibility that failing systems could contribute effluent through subsurface flows to surface waters. The town of Brookside is also predominantly on septic systems and could contribute TP loads to the Santa Clara River.

Homes in Brookside with septic systems are located adjacent to the Santa Clara River.

3.7 Exotic Vegetation

Tamarix, also known as salt cedar, (*Tamarix ramosissima, Tamarix chinensis, and Tamarix ramosissima x chinensis*) is a non-native species that has established itself throughout many parts of the Southwest, including in the Virgin River watershed. Tamarix have taken over much of the Virgin River watershed riparian corridors and are especially dense in the lower portions of the watershed and on the main stem of the Santa Clara River. Tamarix roots deeper than most native vegetation and is therefore able to survive in riparian corridors with lower groundwater tables and is able to withstand extended drought conditions better than most native vegetation. In addition, Tamarix is able to germinate and seed when many native plants cannot.

The presence of Tamarix is exacerbated by the fact that peak flood flows in many Southwestern streams are greatly diminished due to diversions for agricultural and domestic water uses. The delaying or elimination of spring flood flows suppresses the recruitment of natural vegetation, such as cottonwoods and willows. Tamarix is also able to survive in heavily grazed areas due to its low palatability to cattle.

Tamarix is both a direct and indirect source of increased TDS to surface waters. First, Tamarix excretes salt as it grows and these salts are deposited within the riparian corridor and are thus able to be absorbed back into the water column (Stromber et al., 2002). Secondly, Tamarix trees are an indirect source of impairment because of the relatively large quantities of water they consume compared to native vegetation. This water is lost to evapotranspiration rather than being available to the stream. A study by

Texas A&M University and the Texas Agricultural Experiment Station found that one acre of salt cedar will transpire three acre-feet of water per year (0.004 cfs) (Clean Rivers Program, 2002). This can lead to reduced flows and higher salinity concentrations in areas where the riparian corridor is densely populated with Tamarix.

3.8 Sand and Gravel Mining

Several sand and gravel mining operations exist with the Virgin River watershed. A few of these operate in active stream channels and therefore might contribute to increased streambank erosion. Although these operations remove some sediments from the stream, they also change the natural pattern and profile of the channel. It is generally accepted within the scientific community that such changes will result in the channel attempting to re-establish equilibrium with itself during bankfull flood events. Such re-establishment is likely to result in increased suspended sediment loads as the channel migrates laterally and increased bank erosion and bed scour occurs.

Aerial view of the sand and gravel mining operation in the Santa Clara River above Gunlock Reservoir.

3.9 Urban runoff

Urban runoff from cities in the Virgin River watershed is a potential source of several pollutants. Urban runoff includes not only the runoff that occurs during precipitation events, but also includes dry weather flows resulting from lawn and golf course irrigation. Both stormwater and dry weather flows can be elevated in TDS and other pollutants due to the use of lawn care fertilizers and herbicides. These chemicals are dissolved by the water and carried through the stormwater system to the Virgin River and/or its tributaries. DWQ sampling of stormwater outfalls in St. George have resulted in concentrations of TDS greater than 4,000 mg/L.

Aerial view of the Virgin River near St. George.

Dry weather flows near golf course.

3.10 Miscellaneous Sources

Other miscellaneous sources of impairment were identified throughout the watershed. These include construction site disturbances, impacts associated with all terrain vehicles (ATVS), reservoir management, and road salting.

A large number of construction sites are located in the vicinity of St. George and can be sources of excessive erosion. Proper use of silt fences, detention basins, and other management practices can help to reduce the impact that short-term construction and development may have on the water quality in the Virgin River watershed.

Rapid population growth has resulted in increased construction and development in St. George.

There are a total of 42 reservoirs/dams listed in the Lower Colorado River watershed, with 36 occurring within the Virgin and Santa Clara River watersheds. Several of these are large operations that have the potential to significantly affect downstream hydrology and water quality. Evaporation from these reservoirs is a potential source of salinity because the salts are concentrated in the reservoirs when water evaporates. This phenomenon is more significant in the wide, shallow reservoirs.

4.0 TECHNICAL ANALYSIS

This section discusses the approach that was used to estimate loading capacities and existing pollutant loadings for the listed stream segments and reservoirs within the Virgin River watershed. It also presents the methodology that was used to estimate the magnitude of loadings from each source category. These analyses are critical to the TMDL development process because they provide information on the extent to which existing loads are too high, and also because they provide recommendations for prioritizing implementation activities.

4.1 Derivation of Loading Capacity and Existing Loads: Streams

The loading capacity is defined as the amount of a pollutant that can be assimilated by a waterbody so that water quality standards are attained and maintained. There are two basic options for estimating loading capacities and allowable loads: applying a computer model to simulate conditions within the watershed, and (2) using the available water quality and flow data and statistical analysis.

A computer model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models are also capable of simulating in-stream processes using the land-based calculations as input. Once a model has been adequately set up and calibrated for a watershed it can be used to quantify the existing loading of pollutants from subwatersheds or from land use categories. Models can also be used to assess the potential benefits of various restoration scenarios (e.g., implementation of certain best management practices).

Two significant challenges were associated with setting up and calibrating a watershed model for the Virgin River watershed. First among these is the significant number of diversions, canals, and other irrigation pathways that have altered the natural flow of the river. Existing models have limited ability to simulate such a system. Another challenge was posed by the impact that snowmelt has on runoff and streamflow for certain parts of the watershed for certain periods of the year. Existing models are not always able to adequately simulate snowmelt events.

Because of the challenges associated with setting up and calibrating a watershed model for the watershed, a statistical approach was used to develop the loading capacities and existing loadings. The advantages to using a statistical approach are that it accurately identifies the allowable and existing loads, allows one to use data for all flow and loading conditions, and provides insight into the critical conditions. The disadvantages to using a statistical approach are that is provides limited information regarding the relative sources of the loads and does not allow one to simulate the impact of best management practices. These disadvantages were addresses in several ways as described below.

The following steps were taken to implement the statistical approach for the Virgin River TMDLs:

1. A flow duration curve for each segment was developed using the available flow data. This was done by generating a flow frequency table that consisted of ranking all of the observed flows from the least observed flow to the greatest observed flow and plotting those points.
2. The flow curve was translated into a load duration (or TMDL) curve by multiplying each flow by the water quality standard and a conversion factor and plotting the resulting points.
3. Each water quality sample was converted to a daily load by multiplying the sample concentration by the corresponding average daily flow on the day the sample was taken. The load was then plotted on the TMDL graph.

4. Points plotting above the curve represent deviations from the water quality standard and unallowable loads. Those plotting below the curve represent compliance with standards and represent allowable daily loads.
5. The area beneath the TMDL curve is the loading capacity of the stream. The difference between this area and the area representing current loading conditions is the load that must be reduced to meet water quality standards.
6. Average annual loads were calculated by using a weighted-average approach based on the total number of days associated with each flow percentile.

Although the load duration approach does not directly provide information on the source of pollutant loads, it can help to identify the issues surrounding the impairment and roughly differentiate between sources (Figure 4-1). Loads that plot above the curve in the 1 percent to 15 percent flow ranges (low flow conditions) are likely indicative of constant discharge sources such as wastewater treatment plants, septic systems, or irrigation return flows. Those plotting above the curve between 15 percent and 90 percent likely reflect wet weather contributions associated with erosion and washoff processes. Some combination of the two source categories lies in the transition zone of 15 to 30 percent. Those plotting above the curve in the less than 1 percent and greater than 90 percent flow ranges reflect extreme hydrologic conditions of drought or flood, respectively.

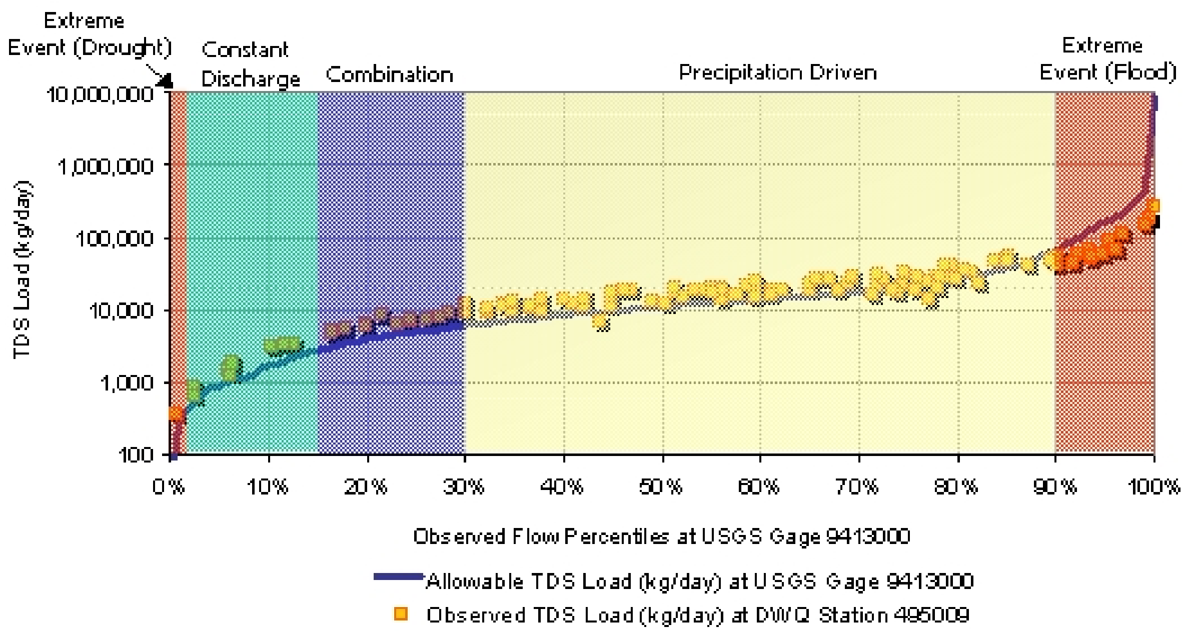


Figure 4-1. Illustration of source information provided by a load duration curve.

Table 4-1 identifies the listed stream segments along with the DWQ water quality monitoring sites and the accompanying USGS gage used to develop a load-duration curve for each stream segment. The DWQ and USGS monitoring sites are shown in Figure 4-2.

Table 4-1. Water quality and stream flow stations used in the load duration curve development.

Stream Segment	DWQ Ambient Water Quality Station (Period of Record)	USGS Stream Flow Station (Period of Record)
Virgin River (AZ/UT State line to Santa Clara River confluence)	495002 (8/1/84 to 5/1/02)	9413500 (10/1/50 to 9/30/00)
Virgin River and Tributaries (from Santa Clara River to the Quail Creek Pipeline Diversion)	495032 (2/24/82 to 6/12/02	9408150 3/1/67 to 9/30/00)
Santa Clara River (Virgin River to Gunlock Reservoir)	495009 (5/8/75 to 6/12/02)	9413000 (10/1/50 to 9/30/00)
North Creek (confluence of Virgin River to headwaters)	495089 (4/3/96 to 6/12/02)	9405900 (12/1/84 to 9/30/93)

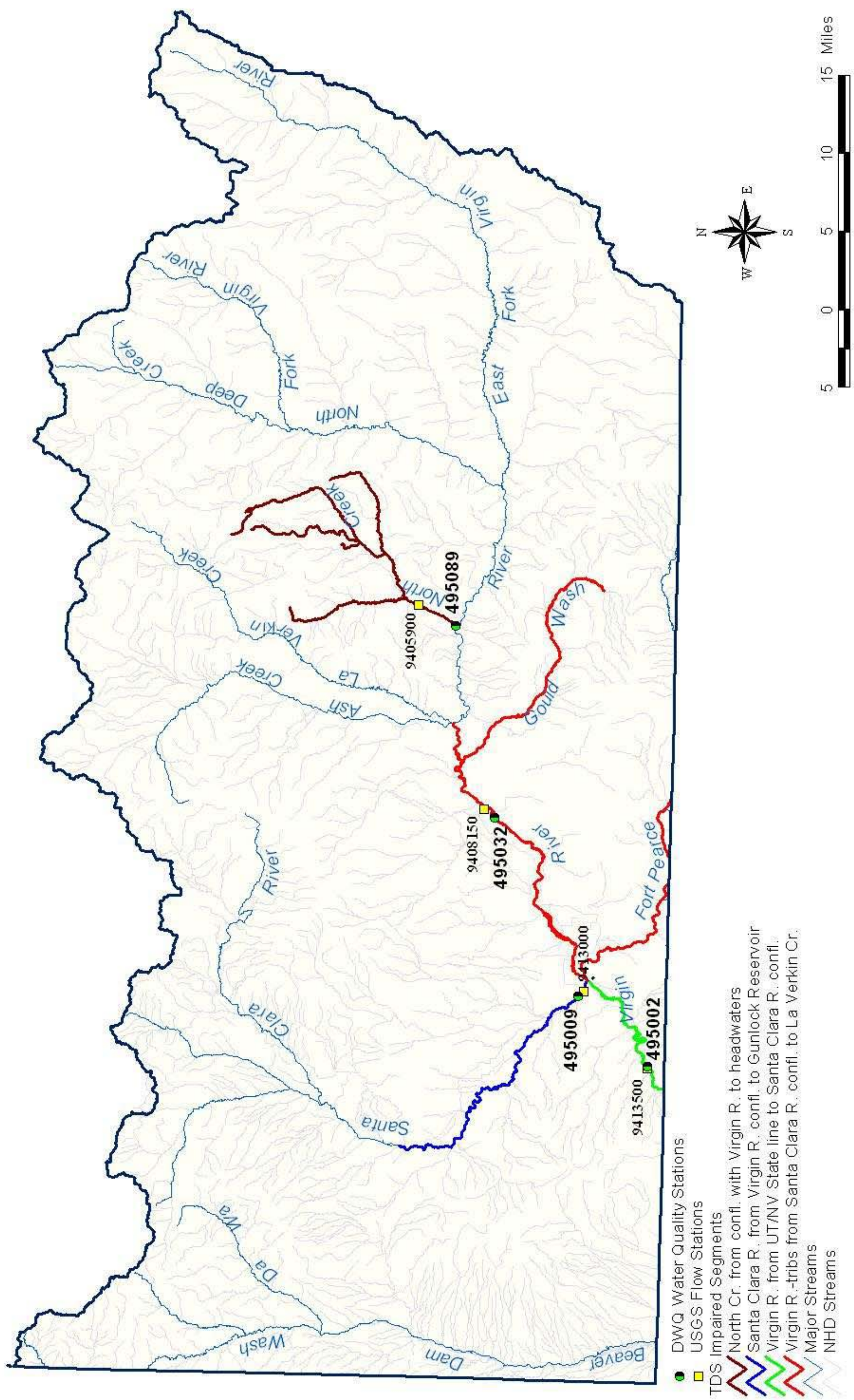


Figure 4-2. Utah DWQ water quality monitoring sites and USGS stream flow gage sites

4.2 Derivation of Loading Capacities: Reservoirs

It is not possible or appropriate to use the load duration curve approach to derive loading capacities for reservoirs. For this reason the BATHTUB model was selected for evaluating water quality in Baker Dam and Gunlock Reservoirs. BATHTUB performs steady-state water and phosphorus balance calculations in a spatially segmented hydraulic network, which accounts for advective and diffusive transport, and nutrient sedimentation. In addition, the BATHUB model automatically incorporates internal phosphorus loadings into its calculations. Eutrophication-related water quality conditions are predicted using empirical relationships previously developed and tested for reservoir applications (Walker, 1985). BATHTUB was determined to be appropriate because it addresses the parameter of concern (phosphorus and dissolved oxygen) and has been previously recommended by USEPA for the development of TMDLs (USEPA, 1999).

4.3 Estimating Loads from Each Source Category

Once the existing and allowable loads were calculated for each stream segment or reservoir, separate analyses were performed to estimate the magnitude of the existing loadings from each significant source category. Information on the sources of existing loadings is critical to identifying and implementing successful management measures, or deciding that the cause of the impairment is primarily due to natural sources.

Several methods were used to estimate the loads from each source category and are explained below. Relatively good information existed to estimate loads from some sources for some pollutants. In other cases the available information had to be used in combination with best professional judgment to arrive at a load estimate. In these situations a variety of information was used to assess the relative magnitude of the source categories. For example, the results of the load duration analysis were used to obtain clues as to whether constant discharges or wet weather sources were more significant.

4.3.1 Irrigation Return Flows

Diverted water in the Virgin River watershed is generally used for irrigation and irrigation practices in the watershed are a potential source of several pollutants of concern. Irrigation return flows can acquire nutrients and salinity from fields. Flood irrigation in particular is potentially a major source pollutants because of the large amounts of water used in the process.

To assess the contribution of TDS and TP from irrigation in a listed segment the number of acres of irrigated land in that segment was multiplied by the volume of water applied per year, the average irrigation efficiency in that segment of the river, a factor representing the portion of unconsumed irrigation water returning to the stream segment, and a value representing the increase in concentration of TDS or TP associated with returned irrigation water.

Irrigation return flows from the Washington Fields area.

The volume of water applied per year was assumed to be 40 inches based on recommended consumptive use guidelines published by the Utah State University Extension (Hill and Koenig, 1999). The consumptive use guidelines vary by region and crop, but 40 inches was chosen as a representative value.

Average efficiencies for each area of the watershed were chosen based on the dominant irrigation type. Flood irrigation was assumed to have an average efficiency of 40 to 50 percent whereas sprinkler irrigation was assumed to have higher efficiencies (60 to 70 percent). It was assumed that 50 percent of unconsumed irrigation water returns to the Virgin River based on an intensive study of the Sevier River watershed (UDNR, 1995)
.

Very little information exists regarding the concentration of TDS in irrigation return flows. A literature search was conducted and resulted in only a few studies with information on this topic. One (USDI, 2001) reported that 3.65 tons of TDS loading is attributable to each acre-foot of irrigation return flow. This equates to a concentration of approximately 2,700 mg/L. However, this value includes the salinity that existed in the irrigation water prior to when it was applied and is also not site-specific to the Virgin River watershed. An increase of 1,000 mg/L TDS associated with irrigation return flows was therefore chosen for the Virgin River TMDLs based on available water quality sampling data in the watershed above and below irrigated lands. For example, the average TDS concentration at the Virgin River below the Washington Fields Canal (station 495026) is 1,016 mg/L and the average TDS concentration at the Virgin River southeast of St. George (station 495020) is 1,955 mg/L.

It should also be noted that there is a poor linkage between salt load reductions and corresponding instream TDS concentrations. Salt load reductions will usually result in lowered instream concentrations, but the magnitude of the reduction is not always assured. Therefore this TMDL report recommends proceeding with BMPs to try and achieve the necessary reductions in TDS concentrations. However, the adoption of site-specific criteria is still a possibility if meeting the existing criterion proves to be infeasible.

4.3.2 Livestock

Cattle grazing was observed in several areas of the watershed during the field reconnaissance. Poor management practices, including feedlot runoff, overgrazing, poor manure management, and grazing in and around streams represent a potentially significant pollutant source, especially for TP.

Animal Feeding Operation along Muddy Creek.

To assess the contributions from these operations on water quality, estimates were made of the number of livestock in each segment of the river. These were based on the latest U.S. Department of Agriculture Census data, the results of the field assessment, and information provided by the Utah Farm Bureau. The number of each type of animal was multiplied by the TP concentration in its manure (expressed on a per kg basis) (NRCS, 1999), a representative animal weight, and a 5 percent factor to account for the portion of the manure that is available to runoff the feeding operation to the stream (Koelsch and Shapiro, 1997). The Utah Farm Bureau provided the information summarized in Table 4-2 regarding livestock in the watershed. This information was unfortunately not available at smaller than the watershed scale.

Table 4-2. Results of AFO/CAFO inventory for the Virgin River watershed.

Operation Type and Size	Total Number	Distance to Nearest Waterway (Feet)						
		Unknown	< 100	100 to 500	500 to 1000	1000 to 2000	2000 to 5000	> 5000
AFO < 300 Animal Units	49	1	4	11	1	8	4	20
Neither AFO or CAFO < 300 Animal Units	12	1	2	4	1	1	3	
Neither AFO or CAFO > 1000 Animal Units	1						1	
Potential CAFO < 300 Animal Units	6		6					
Potential CAFO 300 to 1000 Animal Units	1		1					

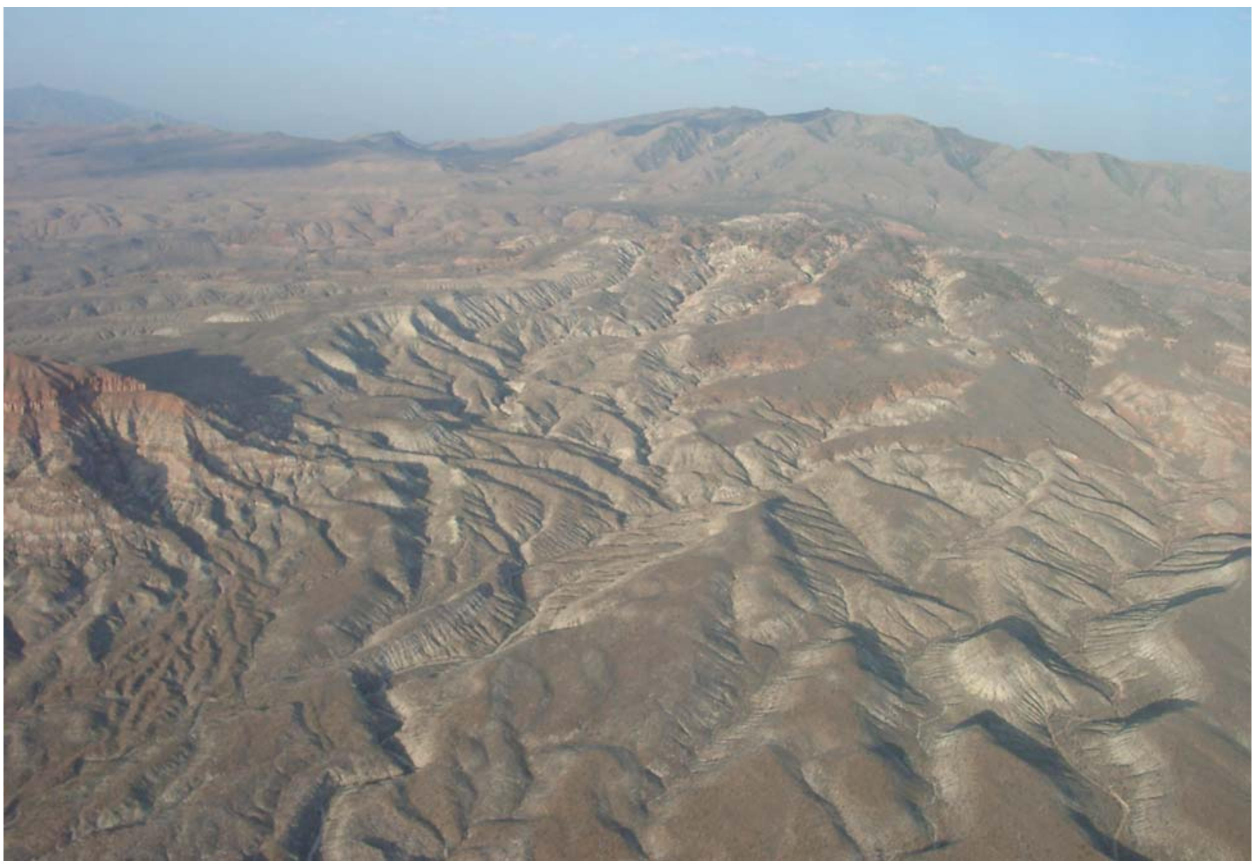
4.3.3 Septic systems

Some residents in the Virgin River watershed use septic systems to treat their domestic wastewater. Septic systems that are properly designed and maintained should not serve as a source of contamination to surface waters. However, septic systems do fail for a variety of reasons. When these septic systems fail hydraulically (surface breakouts) or hydrogeologically (inadequate soil filtration) there can be adverse effects to down gradient surface waters.

Homes on septic system near Pine Valley.

Site-specific information on the location or number of failing septic systems is not currently available for the watershed. Therefore estimates of the loads of TP from these sources were based on the following sources of data and assumptions:

- The total number of septic systems in each portion of the watershed was estimated based on a previous study (Hansen, Allen, and Luce, 1997), the results of the field reconnaissance, and U.S. Census data.
- The population served by each septic system was assumed to be 2.5 persons per household, based on the 2000 U.S. Census (Census, 2000).
- A literature value (265 liters/person/day) was used for the average per capita daily discharge (Horsley and Witten, 1996).
- A literature value of 5 mg/L was used for the TP concentration of septic effluent (USEPA, 2002).
- Best professional judgment was used to estimate septic failure rate depending on site conditions and proximity to surface waters.



Soils in southern Utah are naturally high in erosion during large precipitation events.

4.3.4 Streambank Erosion

Significant quantities of sediment can be mobilized from the bed and banks of active alluvial channels. Metrics of channel stability and bank erosion integrate longer term channel process and fluvial function, and can provide a useful measure of siltation. Because bank erosion is spatially variable on a large scale within a watershed, it is very difficult to apply one approach to provide representative data on status and trends in channel health. Existing watershed models have limited ability to predict streambank erosion, and their usefulness in the Lower Colorado River watershed is compounded by the high number of diversions. Estimates of TDS and TP from streambank erosion were therefore made by assigning that portion of the total loading in a particular segment that was not associated with any other source category to streambank erosion. The results of this approach were then compared against the qualitative information on streambank condition that were made during the field assessment.

Severe natural streambank erosion in the headwaters of the North Fork of the Virgin River.

4.3.5 Urban Runoff

The Simple Method was used to estimate pollutant loadings for urban stormwater runoff and dry weather flows. The Simple Method is a lumped parameter empirical model to estimate nonpoint source pollutant loadings under conditions of limited data availability (Schueler, 1987). The approach relates rainfall and land use to pollutant loading. Data requirements, consisting of land use, land area, event mean pollutant concentrations, and mean annual rainfall, were easily obtainable for the Virgin River watershed. In the Simple Method, the amount of rainfall runoff is assumed to be a function of the imperviousness of various land uses. More densely developed areas have more impervious surfaces, such as rooftops and pavement, which cause more stormwater to runoff rather than be absorbed into the soil. The Simple Method equation is given as:

$$L = (P \times Pj \times Rv/12) \times C \times A \times 2.72$$

where:

L	=	urban runoff load (pounds per time interval, typically annually or monthly)
P	=	rainfall depth (inches) over desired time period
Pj	=	fraction of rainfall events that produce runoff (assumed to be 0.9)
Rv	=	runoff coefficient, which expresses the fraction of rainfall which is converted into runoff.
C	=	event mean concentration of the pollutant (mg/L or ppm)
A	=	area of the watershed (acres)
12	=	conversion factor (inches/foot)
2.72	=	conversion factor (pounds/acre-foot-ppm)

Schueler (1987) developed a relationship between watershed imperviousness and the storm runoff coefficient (Rv):

$$Rv = 0.05 + 0.9(I)$$

where:

I = impervious fraction

The data required to employ the Simple Method were obtained from available GIS and weather data available for the Virgin River watershed. The event mean concentration for TDS was based on sampling of stormwater outfalls conducted by DWQ. The rainfall depth used for residential and urban recreational land uses (e.g., parks and golf courses) was artificially increased to account for lawn watering.

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5.0 WATER QUALITY ASSESSMENT AND TMDL ALLOCATIONS

Water quality data for the Lower Colorado River watershed were obtained from the Utah Department of Environmental Quality, the Washington County Water Conservancy District (WCWCD) and downloaded from the USGS NWIS database. The locations, periods of record, and summary statistics for available water quality data are presented in this section organized by impaired segment. This section also presents the existing and allowable pollutant loads for each listed segment and estimates the contribution of the current loads associated with each major source category. As required by the Clean Water Act, the allowable loads are allocated among wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and background sources, and margin of safety (MOS) to account for uncertainty in the analysis.

5.1 Beaver Dam Wash from Motoqua to the Utah/Nevada State Line

Beaver Dam Wash, from Motoqua to the Utah/Nevada state line, was listed on Utah's 2002 303(d) list as impaired for temperature for the beneficial use of cold water game fish and other cold water aquatic life (3A). However, DWQ determined that the high water temperatures in Beaver Dam Wash are naturally occurring and the listing was due to an incorrect beneficial use designation, rather than an actual water quality impairment. As a result, the segment was de-listed from Utah's 2002 303(d) list based on re-classification of Beaver Dam Wash as a warm water fishery (3B) in the January 6, 2004 R-317-2, Utah Administrative Code. Appendix A presents the results of a vegetative cover and temperature data analysis in the Beaver Dam Wash watershed and describes how this relates to the appropriate beneficial uses.

Riparian corridor of Beaver Dam Wash.

5.2 North Creek from the Confluence with the Virgin River to Headwaters

North Creek enters the Virgin River above the town of Virgin and the headwaters lie in the high terrain of Zion National Park. The valley is comprised of narrow bedrock and is sparsely settled by isolated ranches. Diversions and off-channel ponds are common but the stream is not impounded. The riparian vegetation is robust and largely native. Surrounding hillslopes are dominated by extensive exposures of highly erosive shale formations that contribute to background TDS loads. Current water quality and flow sampling stations are shown in Figure 5-1.

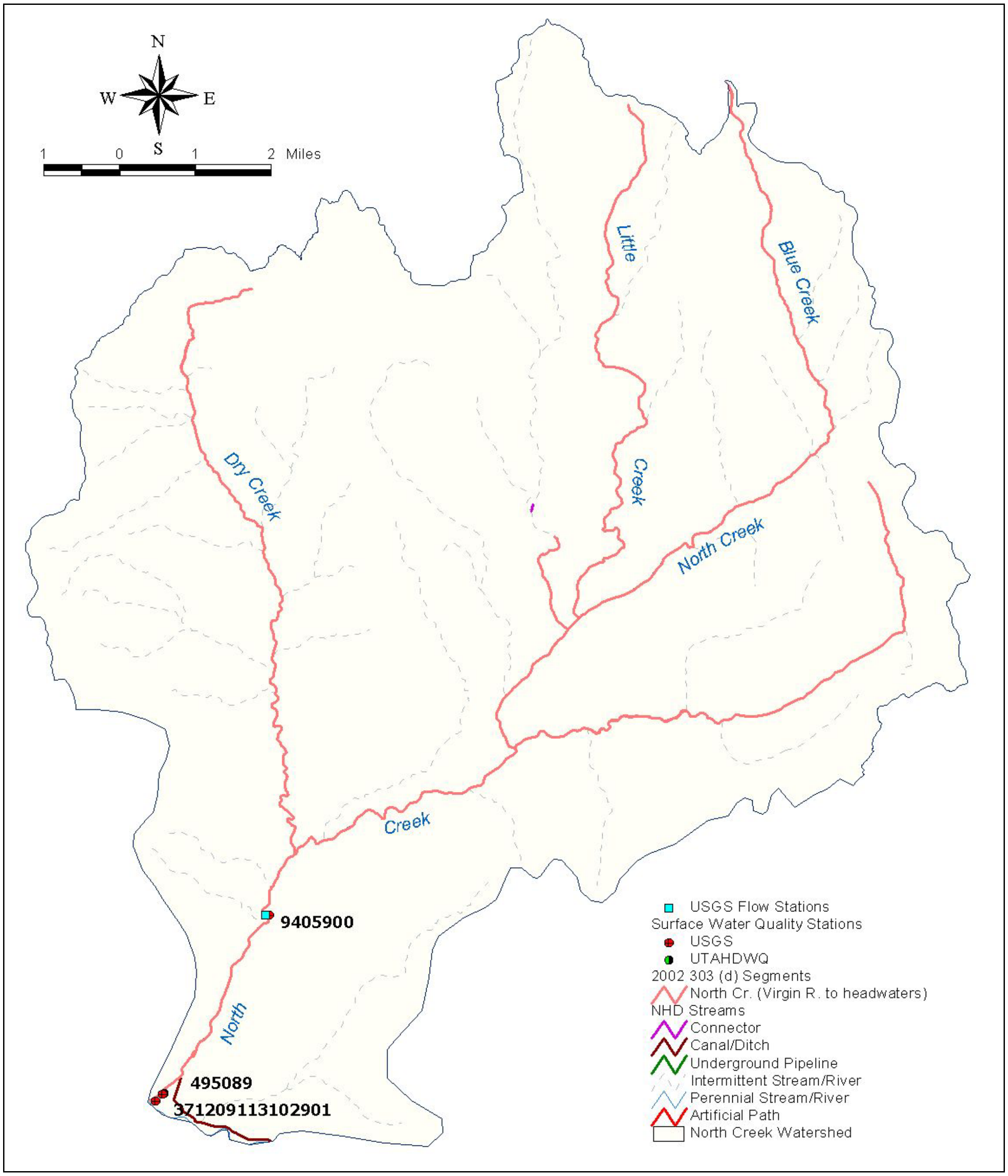


Figure 5-1. Current DWQ and USGS sampling stations in the North Creek subwatershed.

North Creek from its confluence with the Virgin River to its headwaters is listed for TDS and Table 5-1 and Table 5-2 summarize the available TDS data. The data are shown graphically in Figure 5-2 and Figure 5-3. The data indicate an average TDS concentration at the North Creek above the Virgin River confluence station (station 495089) of 1,263 mg/L, which is slightly above the standard of 1,200 mg/L. There does not appear to be a long-term trend in the data. More than 40 percent of the recent samples at this station exceeded the standard. Values for TDS from May to October are usually above 1,200 mg/L.

Riparian corridor of North Creek.

Table 5-1. Summary of TDS data for North Creek.

Station ID/Name	Total # of Samples	Average (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV[1]	First Sample	Last Sample
495089/North Creek above the Virgin River confluence	31	1,263	140	2,376	46%	4/3/96	6/12/02

[1]CV=Coefficient of variation (standard deviation/mean).

Table 5-2. Summary of TDS exceedances for North Creek.

Station ID/Name	Total # of Samples	Total # of Exceedances	Percent Exceeding	Total # of Samples, 1998 to Present	Total # of Exceedances, 1998 to Present	Percent Exceeding, 1998 to Present
495089/North Creek above the Virgin River confluence	31	12	39%	12	5	42%

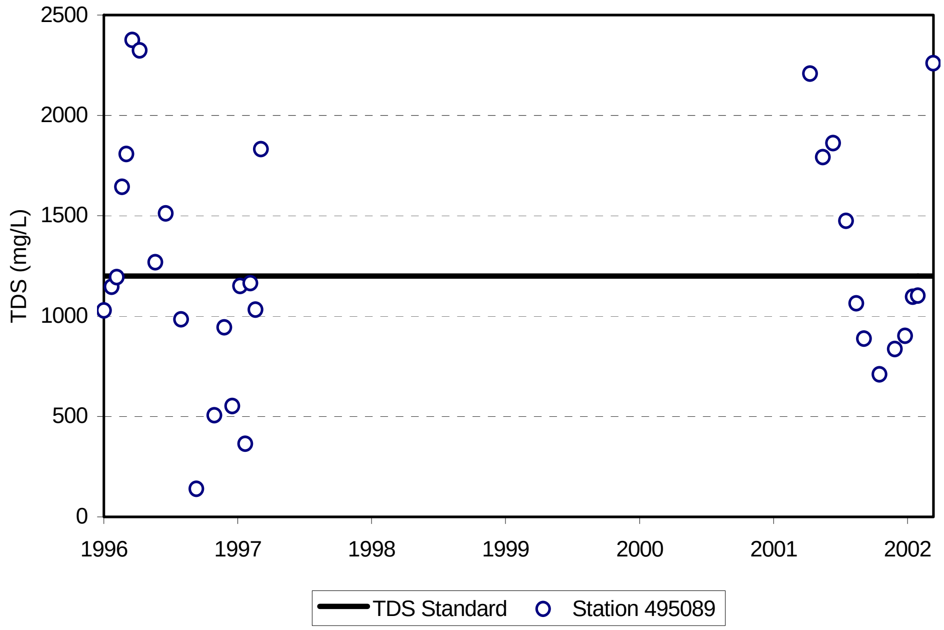


Figure 5-2. All TDS observations for North Creek above the confluence with the Virgin River (Station 495089).

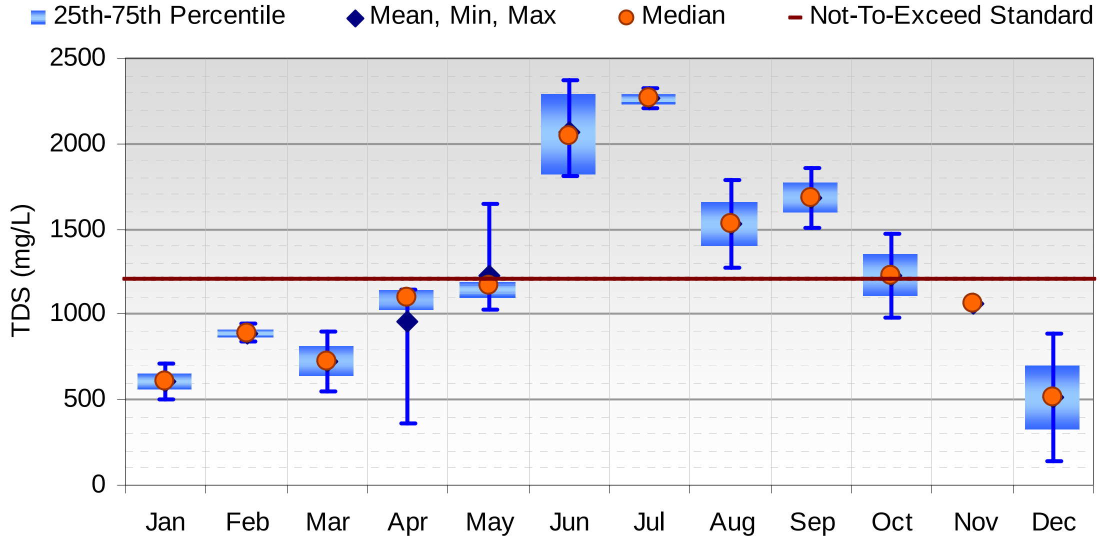


Figure 5-3. Average monthly TDS concentrations for North Creek above the confluence with the Virgin River at station 495089 (1996 to 2002).

Daily flow records for the USGS gage near Virgin (station 9405900) on North Creek are available from December 1, 1984 to September 30, 1993. Water quality data collected by DWQ at the North Creek station above the confluence with the Virgin River (station 495089) are available from April 3, 1996 to June 12, 2002. The period of records for the USGS flow gage and the DWQ water quality station do not coincide with each other. As a result, DWQ instantaneous flow values were used to supplement the USGS daily flow records and the resulting data set was used to perform the load duration analysis.

The results of the load duration analysis are presented in Table 5-3 and Figure 5-4. Table 5-3 presents statistics associated with each flow range, including the sample distribution, median flow, observed concentration, allowed load, existing load and the reduction required to achieve the statewide water quality standard. Table 5-3 and Figure 5-4 show that TDS loads are above the loading capacity primarily during the 10 to 40 percent flow periods, indicating a combination of constant discharge and wet weather sources. Estimates of observed loads during certain flow periods are hampered by the lack of water quality data.

Cattle grazing in the headwaters of North Creek.

Aerial view of the headwaters of North Creek.

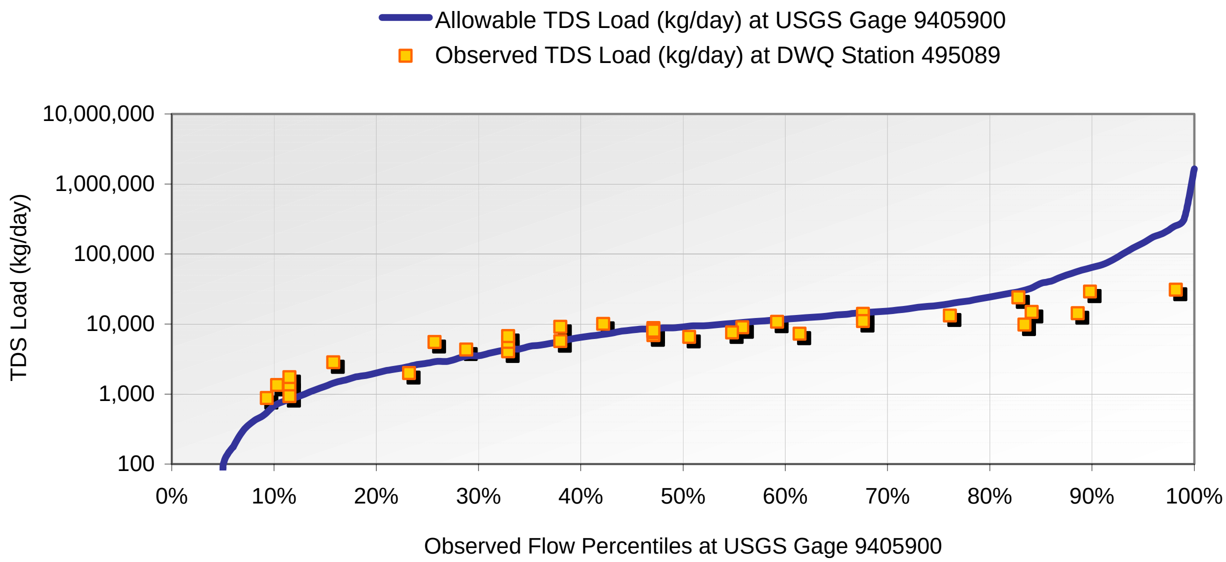


Figure 5-4. Existing TDS loading and loading capacity at station 495089 on the North Creek.

Table 5-3. TDS loading statistics at Station 495089 on the North Creek.

Flow Percentile Ranges	36-Sample Distribution	Median Observed Flow (cfs)	Observed Concentration (mg/L)	Allowable Load (kg/day)	Observed Load (kg/day)	Estimated Reduction (kg/day)	Estimated Reduction (%)
0-10	1	0.03	11,956	88	877	789	90%
10-20	5	0.44	1,256	1,292	1,351	59	4%
20-30	2	0.94	2,406	2,767	5,529	2762	50%
30-40	5	1.63	1,429	4,800	5,696	896	16%
40-50	8	2.8	1,175	8,220	8,044	0	0%
50-60	2	3.5	827	10,276	7,075	0	0%
60-70	7	4.6	981	13,505	11,034	0	0%
70-80	0	6.3	No Data	18,496	No Data	0	No Data
80-90	4	13	612	38,167	19,465	0	0%
90-100	1	49	257	143,859	30,827	0	0%

Based on a review of the available data it is believed that the statewide 1,200 mg/L standard as applied to North Creek is not appropriate. This conclusion is reached based on the following considerations:

- TDS concentrations in streams vary depending on factors such as geology, soils, flow, precipitation, and anthropogenic practices. Concentrations can be naturally high in areas with arid conditions or where geology is easily weatherable, such as is the case with large portions of the North Creek drainage that is composed of highly erosive shale.
- There are few anthropogenic sources of TDS in the drainage (agricultural activities, camping, and ATVs). The ranches are very spread out and their activities (e.g., livestock, off-channel ponds) are not expected to have a significant impact on instream salinity.
- The purpose of the 1,200 mg/L standard is to protect agricultural uses. The ranchers in this area have adapted to the naturally high salinity of North Creek.

A site-specific criterion for North Creek is therefore recommended. USEPA has published limited guidance on the adoption of site-specific criteria. The most current document is EPA's 1994 Interim

Guidance on determination and use of water effect ratios for metals (USEPA, 1994). This document discusses both water effect ratio (toxicity testing) and recalculation (species sensitivity) approaches approved by EPA to modifying a criterion for a site. However, it does not include any guidance on deriving site-specific criteria for TDS or for the protection of agricultural uses. EPA provides for a flexible approach in these situations and recognizes that the methodology that is most appropriate will vary with the type of chemical, toxicology, and designated use. Previous site-specific criteria adoptions in Utah have followed these general guidelines:

- Site-specific numeric criteria may be set equal to natural background where natural background is defined as background concentrations due only to non-anthropogenic sources.
- The 90^{th} percentile of the available representative data can be used to approximate natural ambient water quality conditions and provide some allowance for unknown but minor anthropogenic sources.

An analysis of the potential sources of TDS in the North Creek watershed indicates that anthropogenic sources are between 2 and 3 percent of the total load. This is based on the limited acreage being used for irrigation (approximately 100 acres) and the few other potential anthropogenic sources. The 90^{th} percentile of existing TDS data is therefore recommended as the site specific criterion for North Creek The 90^{th} percentile of data for North Creek is 2,035 mg/L and this value is proposed as a site-specific criterion for North Creek.

Although no TMDL is being recommended for North Creek, BMPs that could be implemented to address the relatively small anthropogenic include livestock management and better control of ATVs (see Appendix B for details).

5.3 Santa Clara River from the Confluence with the Virgin River to Gunlock Reservoir

The Santa Clara River from its confluence with the Virgin River to Gunlock Reservoir was listed for TDS and temperature on the 2002 Section 303(d) list. Selenium is also considered a potential cause of impairment. Flow in the Santa Clara River below Gunlock Dam to Ivins is intermittent and dependent on releases from the reservoir. Uses are a mixture of limited agriculture, livestock, and dispersed recreation. Much of the stream corridor runs through the Shivwits Paiute Reservation and riparian vegetation is a mixture of native and exotic species. Extensive areas of erosive shale formations are evident on the south side of the river.

The Santa Clara River from the City of Santa Clara to the confluence with the Virgin River is considerably more populated than the upper reaches. Historic agricultural fields along the stream are giving way to subdivisions and golf courses. The flood flows are significantly reduced in magnitude and frequency by Gunlock Reservoir storage. The stream channel is relatively stable and well vegetated with native species. A well-developed cottonwood canopy exists through much of the reach. However, recruitment of young cottonwoods, dependent on flood flows, is unknown. Significant thickets of salt cedar are found in the lower reaches near the confluence with the Virgin River. Current DWQ and USGS sampling stations are shown in Figure 5-5.

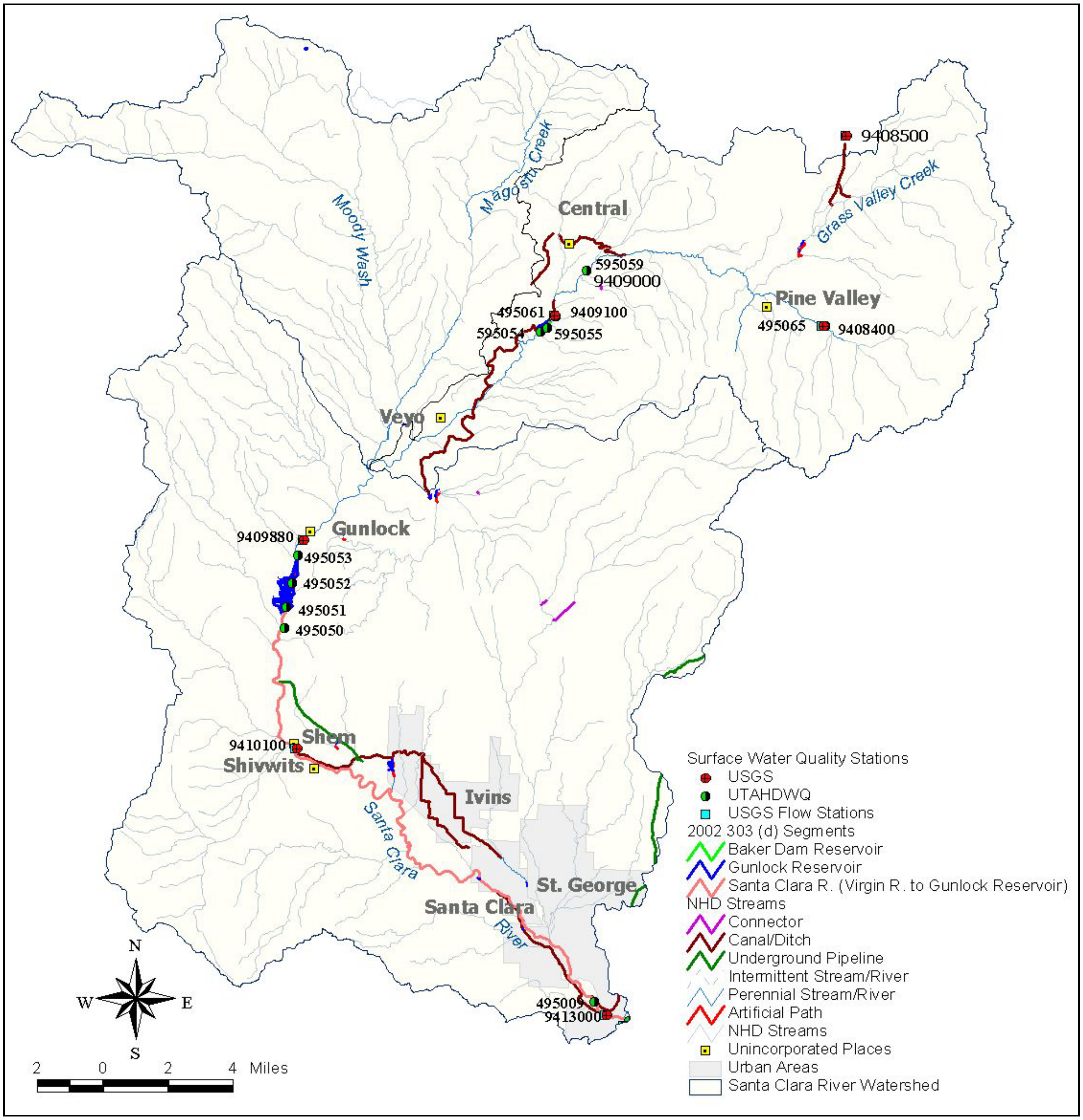


Figure 5-5. DWQ and USGS sampling stations in the Santa Clara River subwatershed.

5.3.1 Santa Clara River: TDS TMDL

Both DWQ and USGS sample numerous stations in the Santa Clara River and the TDS data for all these stations are summarized in Table 5-4 and Table 5-5. The upstream stations have average TDS concentrations below 1,200 mg/L but recent data indicate numerous exceedances (84 percent) of the TDS standard at the Santa Clara River above the Virgin River (station 495009).

Aerial view of the Santa Clara River upstream of the confluence with the Virgin River.

Table 5-4. Summary of all TDS data for the Santa Clara River.

Station ID/Name	Total # of Samples	Average (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV[1]	First Sample	Last Sample
495009/Santa Clara River above Virgin River	170	1,652	294	2,746	35.19%	5/8/1975	6/12/2002
495050/Santa Clara River below Gunlock Reservoir	7	253	183	344	21.22%	5/23/1979	6/13/2002
495053/Santa Clara River above Gunlock Reservoir	44	284	138	400	19.66%	5/24/1979	6/11/2002
495065/Santa Clara River below Pine Valley Reservoir	3	52	48	58	10.18%	5/24/1979	6/25/1993
595059/Santa Clara River above Baker Dam Reservoir	43	175	78	454	34.35%	9/2/1980	6/11/2002

[1]CV=Coefficient of variation (standard deviation/mean).

Table 5-5. Summary of TDS exceedances for the Santa Clara River.

Station ID/Name	Total # of Samples	Total # of Exceedances	Percent Exceeding	Total # of Samples, 1998 to Present	Total # of Exceedances, 1998 to Present	Percent Exceeding, 1998 to Present
495009/Santa Clara River above Virgin River	170	134	79%	31	26	84%
495050/Santa Clara River below Gunlock Reservoir	7	0	0%	5	0	0%
495053/Santa Clara River above Gunlock Reservoir	1	0	0%	0	NA	NA
495065/Santa Clara River below Pine Valley Reservoir	3	0	0%	0	NA	NA
595059/Santa Clara River above Baker Dam Reservoir	43	0	0%	16	0	0%

TDS data for the Santa Clara River above the Virgin River are shown graphically in Figure 5-6 and Figure 5-7. There is an apparent increase in TDS concentrations throughout the period of record but the cause of this increase is unknown; it may be related to the lower flows experienced during this time period. As with most stations in the watershed, TDS concentrations typically increase during the spring and early summer and peak in the late summer.

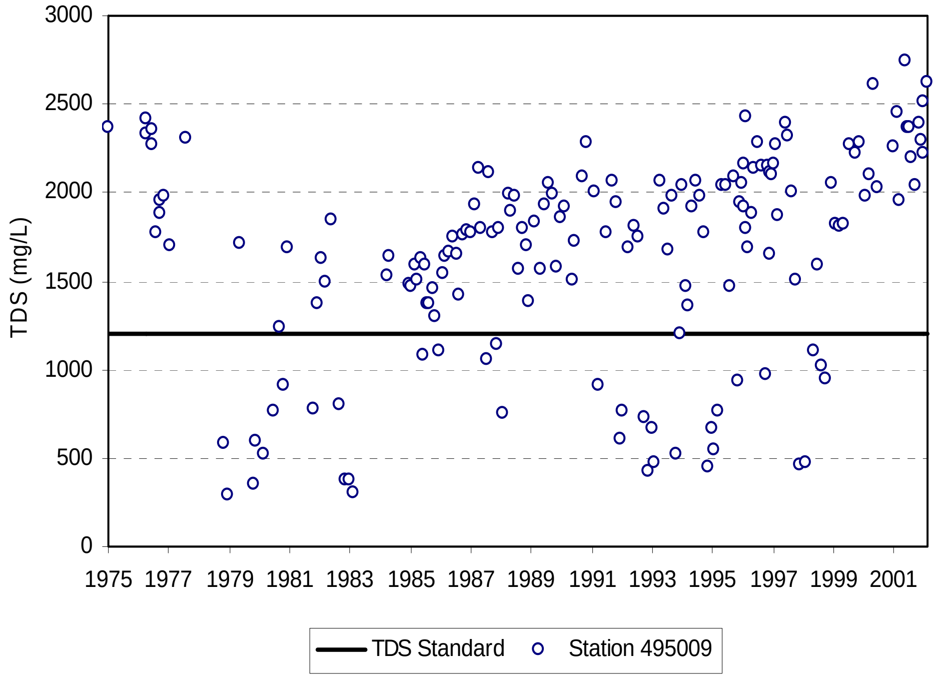


Figure 5-6. All TDS observations for the Santa Clara River above the Virgin River (Station 495009).

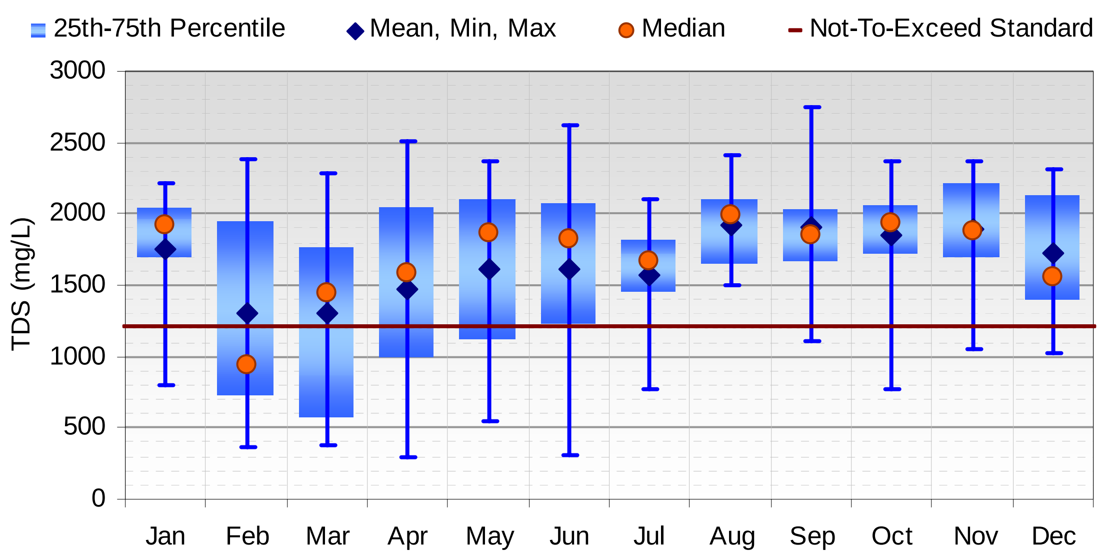
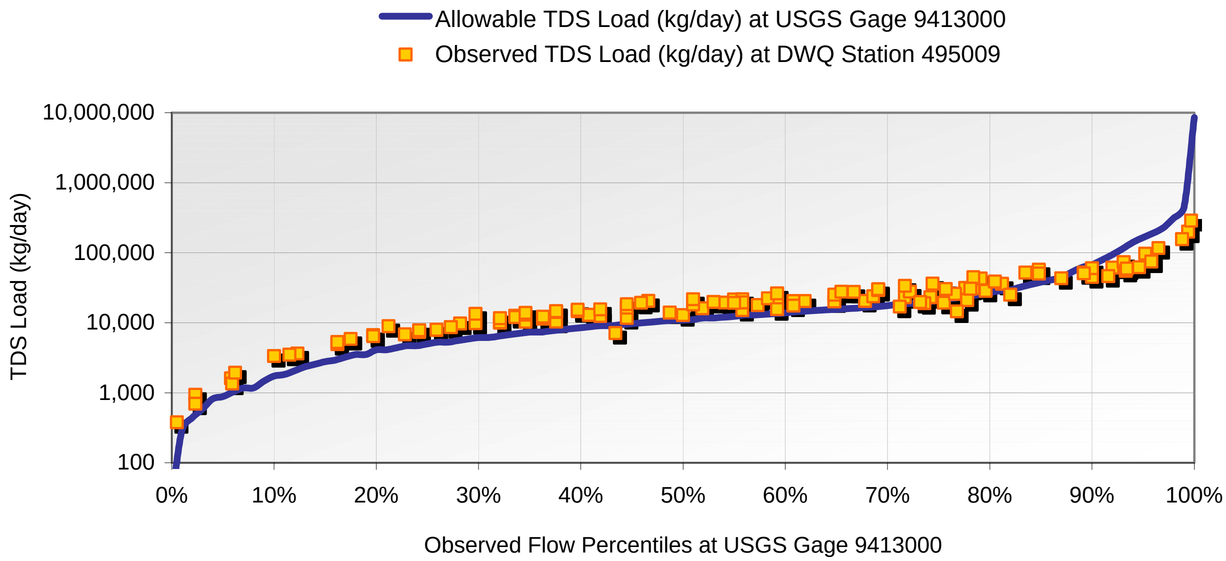


Figure 5-7. Average monthly TDS concentrations for the Santa Clara River above the Virgin River at station 495009 (1975 to 2002).

Aerial view of the Santa Clara River upstream of Gunlock Reservoir.

Daily flow records for the Santa Clara River at St. George, UT USGS gage (station 9413000) are available from October 1, 1950 to September 30, 1956 and from November 19, 1984 to September 30, 2000. DWQ collected samples at Santa Clara River station above the Virgin River (Station 495009) between May 8, 1975 and June 12, 2002. For the period of DWQ sampling where corresponding daily USGS flow is not available (May 8, 1975 to November 19, 1984), paired instantaneous flow values were used to calculate measured load. A total of 124 temporally paired TDS samples and USGS flows are available for the load duration analysis.



The results of the load duration analysis are presented in Table 5-6 and Figure 5-8. They indicate that TDS loads above the loading capacity occur throughout most flow percentiles. The largest load reductions are necessary at the 80 to 90 flow ranges, but reductions are also needed during low flows.

Figure 5-8. Existing TDS loading and loading capacity at station 495009 on the Santa Clara River above the Virgin River.

Table 5-6. TDS loading statistics at Station 495009 on the Santa Clara River above the Virgin River.

Flow Percentile Ranges	124-Sample Distribution	Median Observed Flow (cfs)	Observed Concentration (mg/L)	Allowable Load (kg/day)	Observed Load (kg/day)	Estimated Reduction (kg/day)	Estimated Reduction (%)
0-10	6	0.30	1,562	881	1,146	265	23.1%
10-20	6	0.95	1,849	2,789	4,296	1,507	35.1%
20-30	10	1.70	1,895	4,991	7,877	2,886	36.6%
30-40	18	2.50	1,952	7,340	11,933	4,594	38.5%
40-50	12	3.30	1,857	9,688	14,985	5,296	35.3%
50-60	16	4.20	1,888	12,331	19,388	7,057	36.4%
60-70	14	5.30	1,714	15,560	22,212	6,652	29.9%
70-80	19	7.10	1,603	20,845	27,830	0	25.1%
80-90	9	13.00	1,587	38,167	50,443	12,277	24.3%
90-100	14	56.40	491	165,584	67,760	0	0.0%

Future water quality in the Santa Clara River below Gunlock Reservoir is expected to change as a result of the Santa Clara Pipeline Project. The Pipeline Project was proposed to meet environmental objectives called for by the Virgin Spinedace Conservation Agreement and Strategy. It is intended to make the Santa Clara River between Gunlock Reservoir and the confluence with the Virgin River a priority area for re-establishing population maintenance flows for the Virgin spinedace (USDI, 2002). To meet these flows the Pipeline Project was designed to conserve water from current open-ditch irrigation operations, thereby making water savings available to supply a minimum of 3 cfs of instream flow below Gunlock

Reservoir. The Pipeline Project is also intended to deliver irrigation water to the Shivwits Indian Reservation and to Ivins Reservoir.

The specific impact of the Pipeline Project on downstream flows in the Santa Clara River is not known with certainty due to the complicated hydrology of the study area. A test run between February 13 and March 2, 2002 indicated that 3 cfs of water released from Gunlock Reservoir traveled only about 1.5 to 2 miles downstream of the dam before it was absorbed into the sediment (USDI, 2002). The test results are not considered representative of the possible effects of continuous year-round releases, however, because of the extreme drought conditions that prevailed for some time in southern Utah prior to the test run.

The Pipeline Project also includes three different release points to avoid high infiltration losses in certain segments of the river, such as was observed during the test run. The first release point is at the base of Gunlock Reservoir; the second is located approximately 2.35 miles downstream of the reservoir; and the third is on the Shivwits Reservation, below Windsor Dam. Should data gathered in the future indicate that alternating the point of release for all or a portion of the 3 cfs would provide greater benefits, the Pipeline Project will be adaptively managed to achieve these goals.

The Environmental Assessment for the Pipeline Project (USDI, 2002) made the following conclusions about stream flows after construction of the Project:

- During periods when the river has been dry in the past, there would be instream flows of at least 3 cfs below Gunlock Reservoir throughout the year, an increase over the current 1 cfs of seepage from Gunlock Dam, which consistently dries up before it gets more than a quarter mile downstream from the dam.
- Downstream of Winsor Dam, inflow to the stream (derived from springs, precipitation, and return irrigation flows) would augment stream flows, providing even greater instream flow volumes at this point through the Shivwits Reservation.
- Channel forming flows would still occur downstream of Gunlock Reservoir whenever precipitation events augment stream flow and spills overtop the Gunlock Dam spillway.

Based on these conclusions a revised load duration analysis was conducted to evaluate the potential impact of the Pipeline Project on TDS concentrations in the Santa Clara River below Gunlock Reservoir. A load duration analysis was conducted by replacing all historical flows of less than 3 cfs at USGS gage 9413000 with 3 cfs. These results are shown in Table 5-7 and indicate slightly improved, but still impaired, TDS conditions in the Santa Clara River. A TMDL is therefore still determined to be necessary.

Table 5-7. TDS loading statistics at Station 495009 on the Santa Clara River above the Virgin River, following implementation of the Pipeline Project.

Flow Percentile Ranges	124-Sample Distribution	Median Observed Flow (cfs)	Observed Concentration (mg/L)	Allowable Load (kg/day)	Observed Load (kg/day)	Estimated Reduction (kg/day)	Estimated Reduction (%)
0-10	11	3.00	1,353	8,808	9,924	1,116	11.2%
10-20	11	3.00	1,353	8,808	9,924	1,116	11.2%
20-30	12	3.00	1,353	8,808	9,924	1,116	11.2%
30-40	12	3.00	1,353	8,808	9,924	1,116	11.2%
40-50	10	3.60	1,970	10,569	17,341	6,772	39.1%
50-60	15	4.50	1,765	13,212	19,421	6,209	32.0%
60-70	11	5.40	1,814	15,854	23,953	8,099	33.8%
70-80	20	7.20	1,600	21,138	28,161	7,023	24.9%
80-90	10	14.00	1,481	41,102	50,681	9,578	18.9%
90-100	12	62.00	489	182,025	74,085	0	0.0%

Sources of TDS in this segment of the Santa Clara River include loads from Gunlock Reservoir, irrigation return flows, and natural streambank/hillslope erosion. The loads from Gunlock Reservoir actually improve water quality because the concentrations are typically well below 1,200 mg/L. Table 5-8 summarizes the relative magnitude of each of these source categories. The methodology used to estimate these loads was described above and the key assumptions used to derive the estimated loads for the Santa Clara River are listed below:

- 1500 acres of irrigated lands in the watershed
- 40 inches of water applied per year
- 70 percent efficiency for irrigation (primarily sprinkler)
- 50 percent of unconsumed irrigated water returned to the river
- average annual flow from Gunlock Reservoir of 21 cfs and 253 mg/L TDS
- 75 percent of Gunlock Reservoir flows diverted for irrigation
- Concentration in urban runoff/dry weather flows of 400 mg/L TDS based on literature values (Schiff, 1996).

Table 5-8. Summary of the sources of TDS loading in the Santa Clara River from Gunlock Reservoir to the confluence with the Virgin River.

Source Category	Load (kg/yr)	Percent
Streambank Erosion/Land Erosion	6,284,440	77%
Upstream	1,185,420	15%
Irrigation Return Flows	580,350	7%
Stormwater/Dryweather Flows	60,130	1%
Total	8,110,340	100%

The TDS TMDL for this segment of the Santa Clara River is summarized in Table 5-9. The wasteload allocation is for urban storm and dry weather flows for the community of Santa Clara, as required by the storm water Phase II regulations. The volume of flows was estimated using the Simple Method and the allowable load was calculated by multiplying this volume by the 1,200 mg/L standard. These estimates should be revised as the communities further develop their storm water management plans, map their outfalls, and obtain better data. The observed TDS concentrations in urban runoff from a variety of sites in southern California during a 1995 and 1996 study were only 240 to 570 mg/L (Schiff, 1996).

A 24 percent reduction in annual loads is required to achieve the water quality standards. The critical condition is the spring and summer (April to October) because these are the months when TDS concentrations are highest and when water is most likely to be used for irrigation activities. Continued monitoring should be performed to measure the progress of the TMDL. If all reasonable efforts are made to reduce TDS loads and the 1,200 mg/L target still cannot be achieved within 5 to 15 years, a site-specific criterion should be adopted.

Table 5-9. Summary of the TDS TMDL for the Santa Clara River from Gunlock Reservoir to the confluence with the Virgin River.

Expressed as Endpoints						
• 1,200 mg/L instream TDS target				• Reduction in urban dry weather and stormwater flows		
Expressed as Loads						
Existing Load (kg/yr)	**Loading Capacity (kg/yr)**	**WLA (kg/yr)**	**LA (kg/yr)**	**MOS (kg/yr)**	**Reduction (kg/yr)**	**Reduction (Percent)**
8,110,340	6,524,760	180,390	6,018,130	326,240	1,911,820	24%

5.3.2 Santa Clara River: Selenium TMDL

The Santa Clara River from Gunlock Reservoir to the confluence with the Virgin River is not listed for selenium but it is a suspected cause of impairment. Selenium data for the Santa Clara River are summarized in Table 5-10, Table 5-11, Figure 5-9, and Figure 5-10. Only the most downstream station (above the confluence with the Virgin River) has experienced elevated selenium concentrations. Recent data suggest that approximately 67 percent of all samples at this station exceed the 4-day chronic criterion of 4.60 µg/L. Values are typically greatest during late winter and early spring.

Table 5-10. Summary of all selenium data for the Santa Clara River.

Station ID/Name	Total # of Samples	Average (µg/L)	Minimum (µg/L)	Maximum (µg/L)	CV[1]	First Sample	Last Sample
495009/Santa Clara River above Virgin River	51	3.43	0	8.7	79%	8/10/1976	4/17/2002
495050/Santa Clara River below Gunlock Reservoir	3	0	0	0	0%	7/17/2001	5/1/2002
495053/Santa Clara River above Gunlock Reservoir	8	0.17	0	1	245%	5/22/1996	1/16/2002
495065/Santa Clara River below Pine Valley Reservoir	1	0	0	0	0%	6/25/1993	6/25/1993
595059/Santa Clara River above Baker Dam Reservoir	9	0	0	0	0%	5/22/1996	4/16/2002

Table 5-11. [1]**CV=Coefficient of variation (standard deviation/mean). Summary of selenium exceedances for the Santa Clara River.**

Station ID/Name	Total # of Samples	Total # of Exceedances	Percent Exceeding	Total # of Samples, 1998 to Present	Total # of Exceedances, 1998 to Present	Percent Exceeding, 1998 to Present
495009/Santa Clara River above Virgin River	51	17	33%	15	10	67%
495050/Santa Clara River below Gunlock Reservoir	3	0	0%	0	NA	NA
495053/Santa Clara River above Gunlock Reservoir	8	0	0%	1	0	0%
495065/Santa Clara River below Pine Valley Reservoir	1	0	0%	0	NA	NA
595059/Santa Clara River above Baker Dam Reservoir	9	0	0%	0	NA	NA

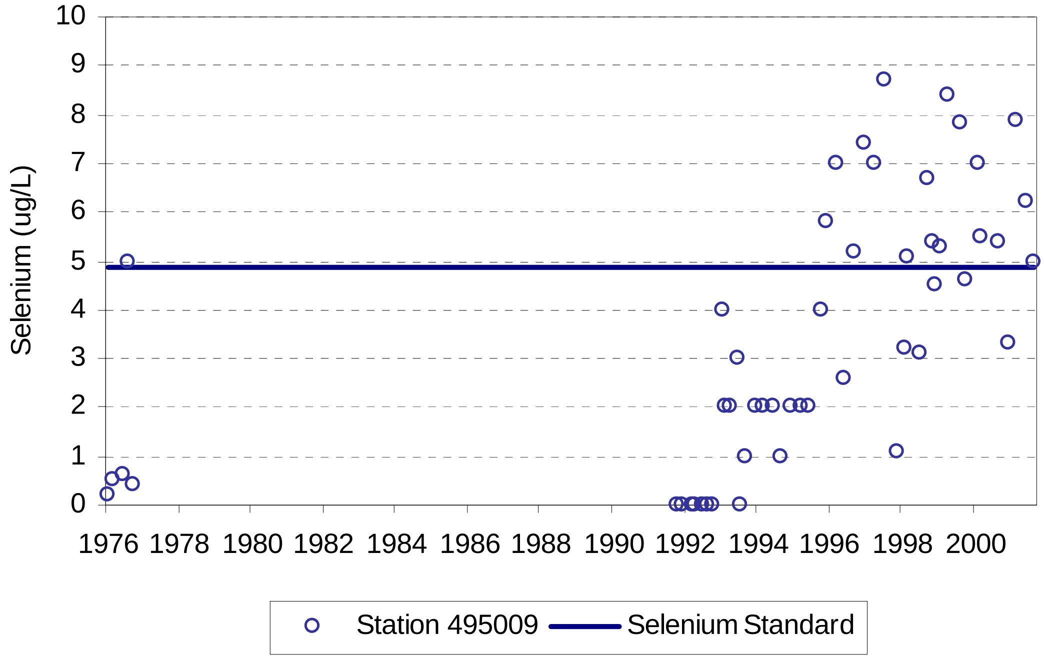


Figure 5-9. All selenium data for the Santa Clara River above the Virgin River at Station 495009.

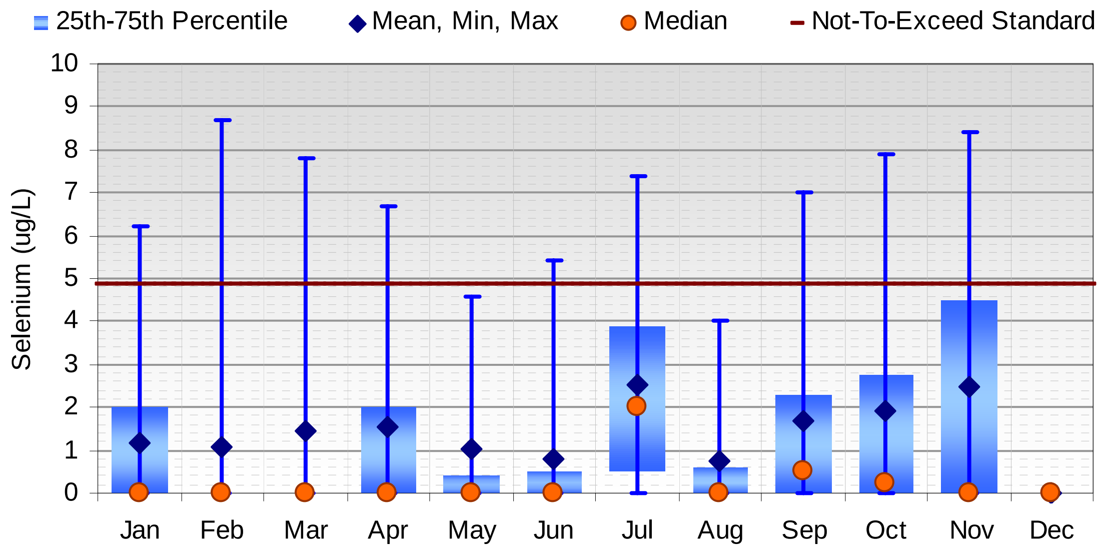


Figure 5-10. Average monthly selenium concentrations for the Santa Clara River above the Virgin River at station 495009.

The results of the load duration analysis for the Santa Clara River, following implementation of the Pipeline Project, are shown in Figure 5-11 and Table 5-12. They indicate that relatively small reductions in loads will be needed for several flow percentiles.

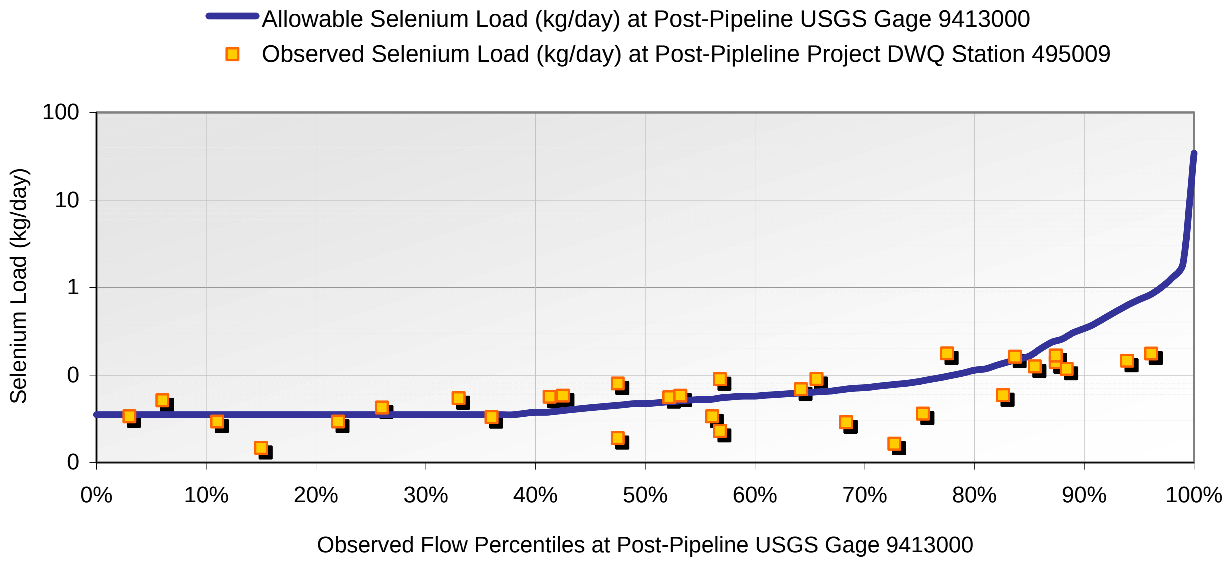


Figure 5-11. Estimated selenium loading and loading capacity at station 495009 on the Santa Clara River, following implementation of the Pipeline Project.

Table 5-12. Selenium loading statistics at Station 495009 on the Santa Clara River, following implementation of the Pipeline Project.

Flow Percentile Ranges	40-Sample Distribution	Median Observed Flow (cfs)	Observed Concentration (ug/L)	Allowable Load (kg/day)	Observed Load (kg/day)	Estimated Reduction (kg/day)	Estimated Reduction (%)
0-10	2	3.00	4.55	0.0352	0.0334	0.0000	0.0%
10-20	2	3.00	4.55	0.0352	0.0334	0.0000	0.0%
20-30	3	3.00	4.55	0.0352	0.0334	0.0000	0.0%
30-40	3	3.00	4.55	0.0352	0.0334	0.0000	0.0%
40-50	4	3.60	6.52	0.0423	0.0574	0.0151	26.3%
50-60	5	4.50	5.07	0.0528	0.0558	0.0029	5.2%
60-70	5	5.40	3.69	0.0634	0.0488	0.0000	0.0%
70-80	4	7.20	2.06	0.0846	0.0362	0.0000	0.0%
80-90	6	14.00	3.87	0.1644	0.1326	0.0000	0.0%
90-100	6	62.00	1.06	0.7281	0.1607	0.0000	0.0%

Sources of selenium in this segment of the Santa Clara River include irrigation return flows, storm and dry weather flows from urban areas, and natural hillslope/streambank erosion. The very limited (two observations) of selenium being discharged from Gunlock Reservoir indicate that upstream sources are not significant. Table 5-13 summarizes the relative magnitude of each of these source categories. The key assumptions used to derive these estimated loads including the following:

- 1500 acres of irrigated lands along the stream valley
- 40 inches of water applied per year
- 70 percent efficiency for irrigation
- 50 percent of unconsumed irrigated water returned to the river
- increase of selenium concentrations due to irrigation of 10 μg/L
- selenium event mean concentration of stormwater and dry weather flows of 2 μg/L (Schiff, 1996)

Table 5-13. Summary of the sources of Selenium loading in the Santa Clara River from Gunlock Reservoir to the confluence with the Virgin River.

Source Category	Load (kg/yr)	Percent
Streambank/Hillslope Erosion	12.98	65%
Irrigation Return Flows	6.60	33%
Stormwater/Dryweather Flows from Phase II Communities	0.30	2%
Total	19.88	100%

The selenium TMDL for this segment of the Santa Clara River is summarized in Table 5-14. The wasteload allocation is for urban storm and dry weather flows, as required by the storm water Phase II regulations. The volume of flows was estimated using the Simple Method and the allowable load was calculated by multiplying this volume by the 4.60 µg/L standard. Only a 9 percent reduction is required to achieve the loading capacity. The critical condition for the load reductions is during the months of March and April when existing concentrations are at their greatest.

Table 5-14. Summary of the selenium TMDL for the Santa Clara River from Gunlock Reservoir to the confluence with the Virgin River.

Expressed as Endpoints						
• 4.6 µg/L instream selenium target			• 4.6 µg/L selenium in urban runoff			
Expressed as Loads						
Existing Load (kg/yr)	**Loading Capacity (kg/yr)**	**WLA (kg/yr)**	**LA (kg/yr)**	**MOS (kg/yr)**	**Reduction (kg/yr)**	**Reduction (Percent)**
19.88	19.03	0.72	17.36	0.95	1.80	9%

5.3.3 Santa Clara River: Temperature Impairment

The Santa Clara River downstream of Gunlock Reservoir is listed for temperature. The available temperature data are summarized in Table 5-15 and Table 5-16. Only a few stations have been sampled since 1982, and the data for these stations indicate average temperatures are between 15 ºC and 18 ºC. Only a few recent temperature readings have exceeded the standard of 27 ºC. Aerial and ground based field surveys revealed a healthy riparian corridor through this section of the Santa Clara River. The most downstream segments have significant numbers of salt cedar, but the majority of the stream course has an adequate riparian corridor, consistent with natural conditions. Stream channel morphology is also representative of natural conditions and is not contributing to excessive temperatures. Based on the current data analysis and the condition of the riparian vegetation and geomorphology of the stream channel, a temperature TMDL is not deemed necessary at this time and de-listing for this parameter is recommended

Table 5-15. Summary of all temperature data for the Santa Clara River.

Station ID/Name	Total # of Samples	Average (ºC)	Minimum (ºC)	Maximum (ºC))	CV[1]	First Sample	Last Sample
495009/Santa Clara River above Virgin River	168	15.8	1.9	32	46%	8/10/76	6/12/02
495050/Santa Clara River below Gunlock Reservoir	7	18.1	13.9	21.07	13%	5/24/79	6/13/02
495053/Santa Clara River above Gunlock Reservoir	45	17.9	3.06	28	34%	5/24/79	8/7/02
495065/Santa Clara River below Pine Valley Reservoir	2	8.0	6	10	35%	5/23/79	6/25/93
595059/Santa Clara River above Baker Dam Reservoir	44	15.1	7.34	23.59	28%	9/2/80	8/7/02

[1]CV=Coefficient of variation (standard deviation/mean).

Table 5-16. Summary of exceedances of the temperature standard for the Santa Clara River.

Station ID/Name	Total # of Samples	Total # of Exceedances	Percent Exceeding	Total # of Samples, 1998 to Present	Total # of Exceedances, 1998 to Present	Percent Exceeding, 1998 to Present
495009/Santa Clara River above Virgin River	168	15	9%	25	1	4%
495050/Santa Clara River below Gunlock Reservoir	7	0	0%	5	0	0%
495053/Santa Clara River above Gunlock Reservoir	45	3	7%	0	NA	NA
495065/Santa Clara River below Pine Valley Reservoir	2	0	0%	0	NA	NA
595059/Santa Clara River above Baker Dam Reservoir	44	0	0%	16	0	0%

The temperature data for station 495009 (Santa Clara River above Virgin River) are shown graphically in Figure 5-12 and Figure 5-13. The data show that most samples are below the standard of 27 ºC, with peak temperatures in July.

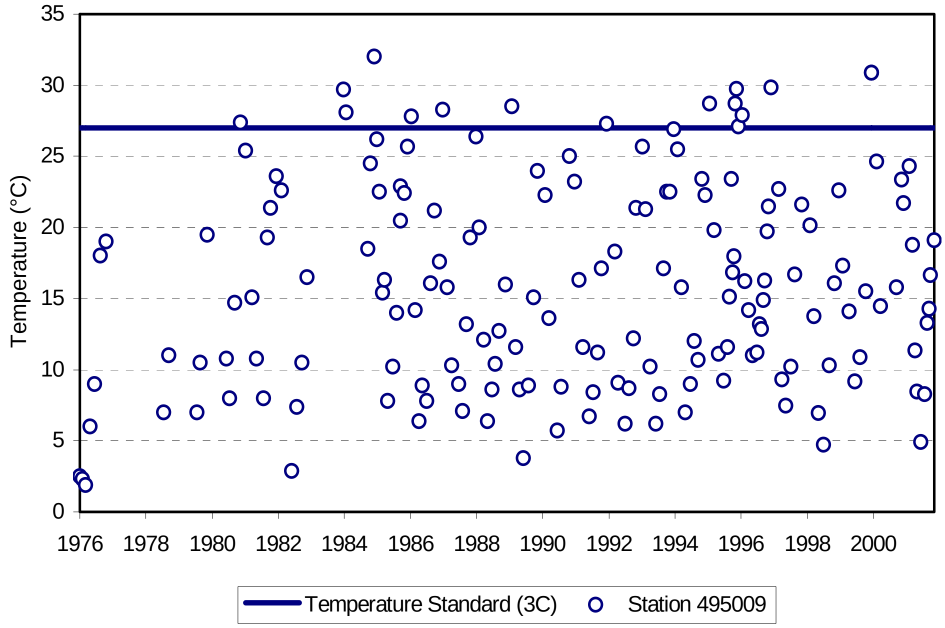


Figure 5-12. All temperature data for the Santa Clara River above the Virgin River (station 495009)

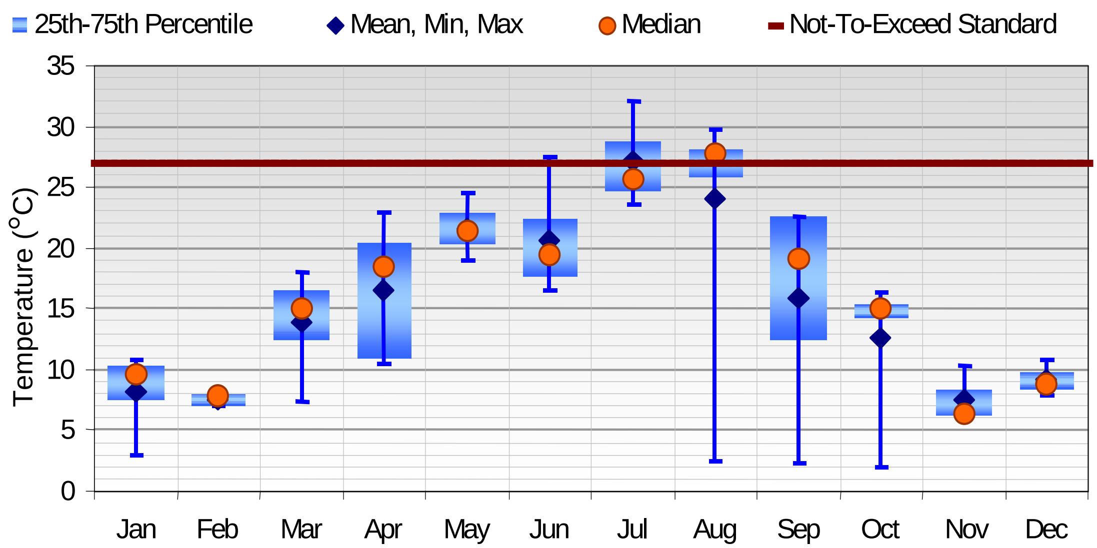


Figure 5-13. Average monthly temperature data for the Santa Clara River above the Virgin River at station 495009 (1976 to 2002).

Based on the available data it does not appear that a temperature TMDL for the Santa Clara River is warranted. Only four percent of the recent samples exceed the standard of 27 ºC, which is within the allowable (ten percent) frequency of exceedances for aquatic life beneficial use support classes.

5.4 Virgin River From Arizona/Utah Border to the Quail Creek Diversion

Two segments of the Virgin River appear on the 2002 303(d) list:

- Virgin River (State line to confluence with Santa Clara River)
- Virgin River and Tributaries (Santa Clara River confluence to La Verkin Creek, except Quail Creek to Leeds Creek)

Between Bloomington and the state line the Virgin River is largely undeveloped. The channel is controlled by a shallow bedrock gorge and the riparian vegetation is dominated by salt cedar. There is some evidence of streambank erosion but few impacts from livestock.

The communities of St. George, Washington, and Bloomington completely surround the reach of the Virgin River between Bloomington and the Washington Fields Diversion. The large agricultural area of Washington Fields lies along the eastern banks. A large portion of the stream flow is diverted during the growing season at the Washington Fields Diversion. The river channel is restricted in width by the lack of flow and extensive growths of exotic salt cedar. Streambank erosion is widespread although very little development takes place within the 100-year floodplain due to strong local zoning codes.

Aerial view of the Virgin River downstream of the confluence with the Santa Clara River.


Virgin River near the confluence of the Santa Clara River.


Washington Fields area, near St. George, with evidence of salt accumulation on the soil surface.

Aerial view of the Quail Creek Diversion on the Virgin River.

The Quail Creek Diversion on the Virgin River.

Base flows in the Virgin River above the Washington Fields Diversion are greater than below the diversion. Flows are somewhat augmented by small releases from Quail Creek Reservoir. The channel is constrained laterally by dense thickets of salt cedar but there are some relatively active floodplains in the lower part of the reach. The Hurricane wastewater lagoons are adjacent to the river.

The majority of base flows in the Virgin River are diverted at the Quail Creek Diversion. Below the diversion, Pah Tempe Springs, a set of natural hot springs along the river, contributes strongly saline water to the river. This reach is relatively unaltered and contained within a wide basalt canyon. There is little or no agriculture adjacent to the river and the riparian vegetation community is a relatively sparse mixture of native cottonwood/willow and salt cedar. Ash and La Verkin Creeks join the Virgin in this reach.

Aerial view of the Virgin River near the Pah Tempe Hot Springs.

The Virgin River from the Arizona/Utah border to the Santa Clara River is listed as impaired due to TDS. Current DWQ and USGS sampling stations area shown in Figure 5-14. The two stations with the most data are those at Bloomington Crossing above the St. George wastewater treatment plant (station 495012) and below the first narrows (station 495002).

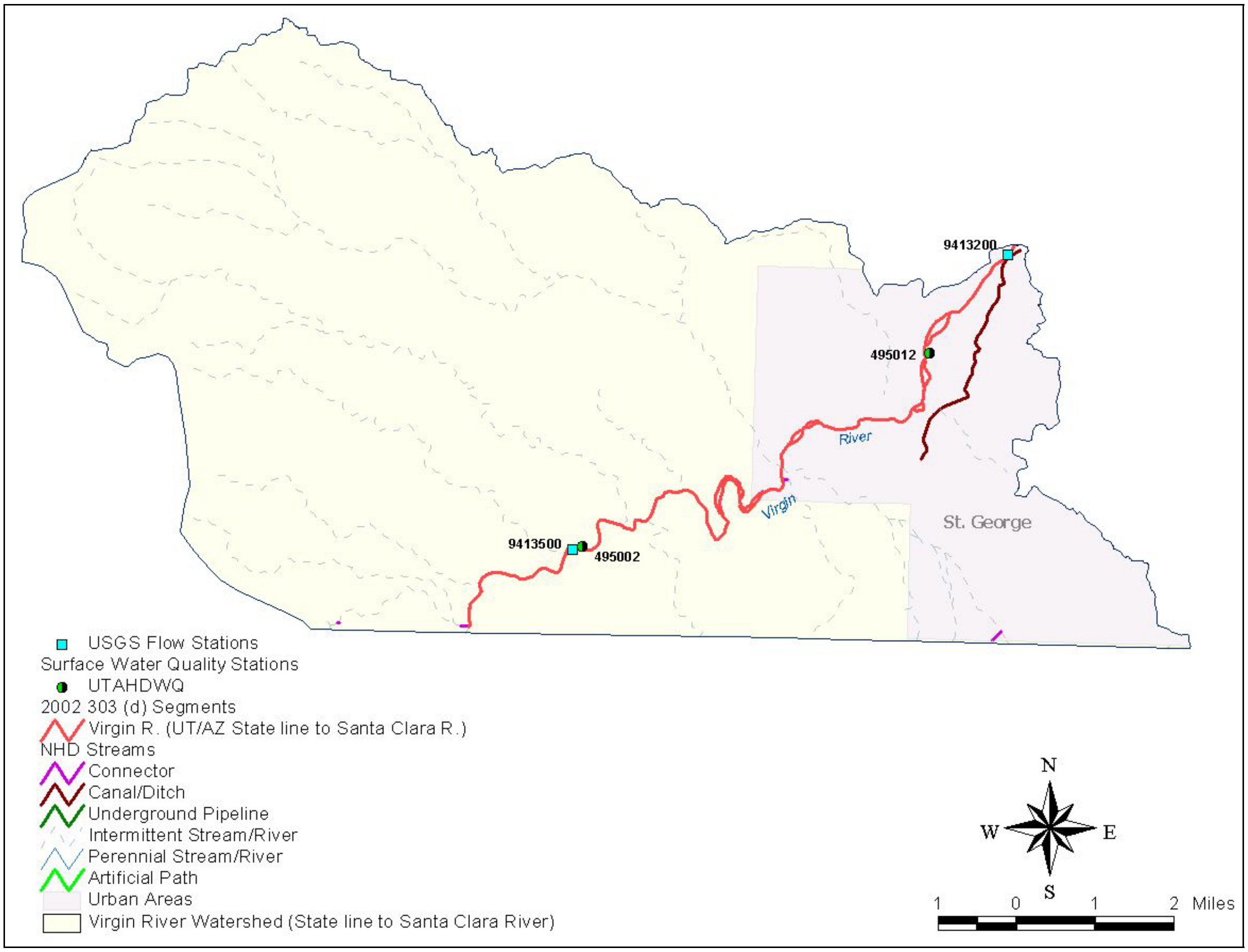


Figure 5-14. DWQ and USGS sampling stations on the Virgin River between the State line and the Santa Clara River.

TDS data for the Virgin River from the Utah border to the confluence with the Santa Clara River are summarized in Table 5-17 and Table 5-18. The average TDS for all stations is above the 1200 mg/L standard, with maximum TDS values at station 495002 (Virgin River below fist narrow) greater than 3,000 mg/L. All recent samples at station 495012 (Virgin River at Bloomington Crossing above St. George waste water treatment plant) and 82 percent of samples at 495002 (Virgin River below first narrows) were above 1,200 mg/L.

TDS data for this segment are shown graphically in Figure 5-15 to Figure 5-17. No apparent long-term trend in TDS concentrations can be observed. TDS concentrations typically increase from April to July and peak in August when flows are at their lowest.

Table 5-17. Summary of all TDS data for the Virgin River from the Utah border to the Santa Clara River.

Station ID/Name	Total # of Samples	Average (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV[1]	First Sample	Last Sample
495012/Virgin River at Bloomington Crossing above St. George WWTP	30	2,197	782	3,216	28%	8/23/77	11/14/01
495002/Virgin River below first narrows	143	1,848	472	3,990	35%	8/1/84	5/1/02

[1]CV=Coefficient of variation (standard deviation/mean).

Table 5-18. Summary of TDS exceedances for the Virgin River from the Utah border to the Santa Clara River.

Station ID/Name	Total # of Samples	Total # of Exceedances	Percent Exceeding	Total # of Samples, 1998 to Present	Total # of Exceedances, 1998 to Present	Percent Exceeding, 1998 to Present
495012/Virgin River at Bloomington Crossing above St. George WWTP	60	56	93%	4	4	100%
495002/Virgin River below first narrows	286	240	84%	56	46	82%

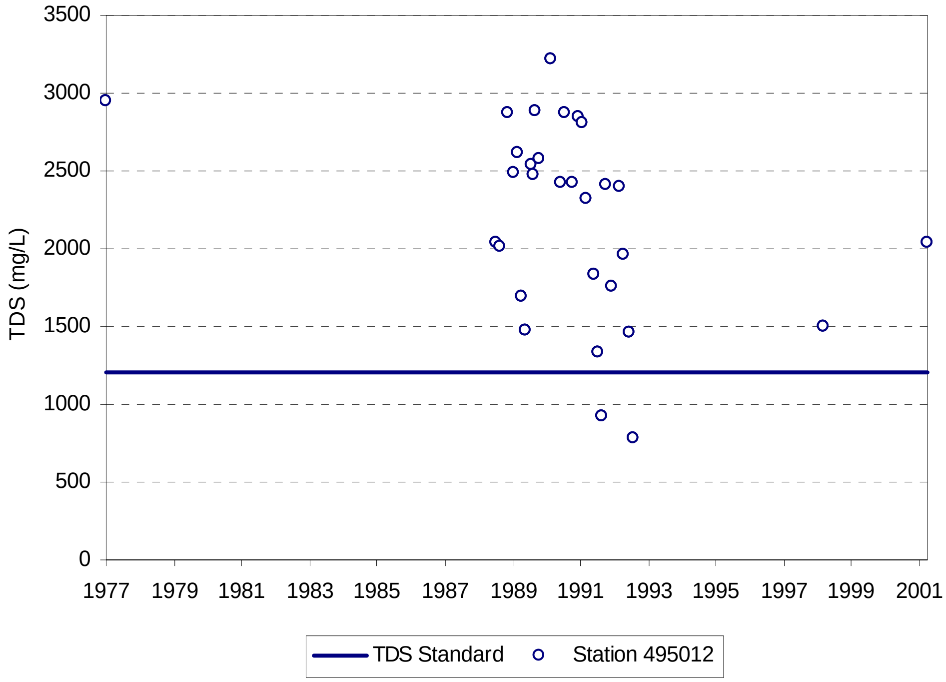


Figure 5-15. All TDS observations for Virgin River at Bloomington Crossing above St. George WWTP (Station 495012).

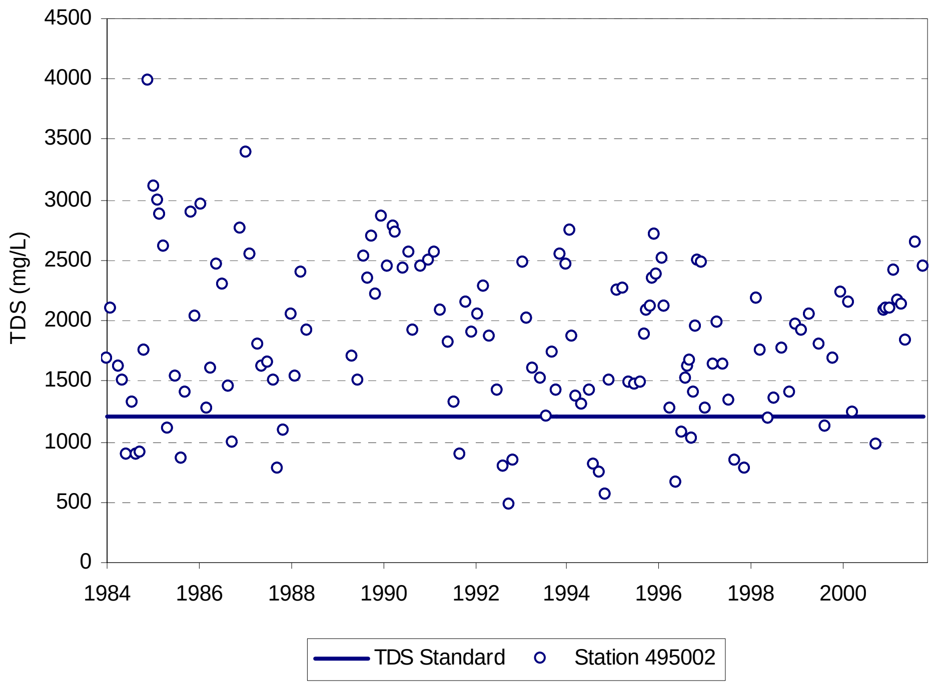


Figure 5-16. All TDS observations for Virgin River below first narrows (Station 495002).

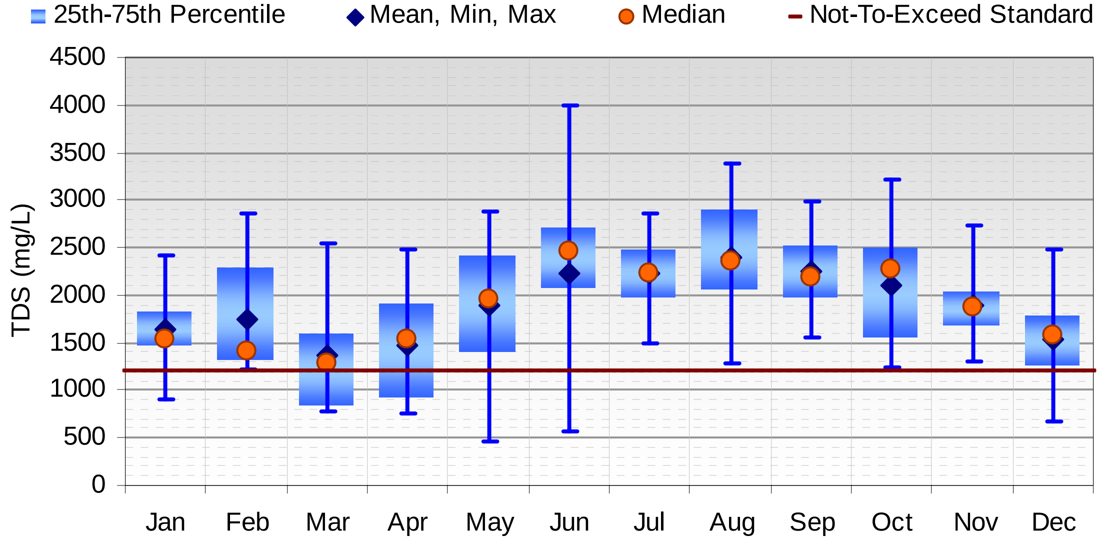


Figure 5-17. Average monthly TDS observations for the Virgin River from the Utah border to the confluence with the Santa Clara River at stations 495012 (Virgin River at Bloomington Crossing above St. George WWTP) and 495002 (Virgin River below first narrows) (1977 to 2002).

The Virgin River and its tributaries (except Quail Creek and Leeds Creek) are listed for TDS from the Santa Clara confluence to the Quail Creek Diversion. Both DWQ and USGS sample numerous stations in these waterbodies (Figure 5-18) and the TDS data for all these stations are summarized in Table 5-19 and Table 5-20. Most tributary stations have average TDS concentrations below the 1,200 mg/L standard whereas most Virgin River stations have TDS concentrations above the 1,200 mg/L standard. There are limited recent sampling data available for most tributaries.

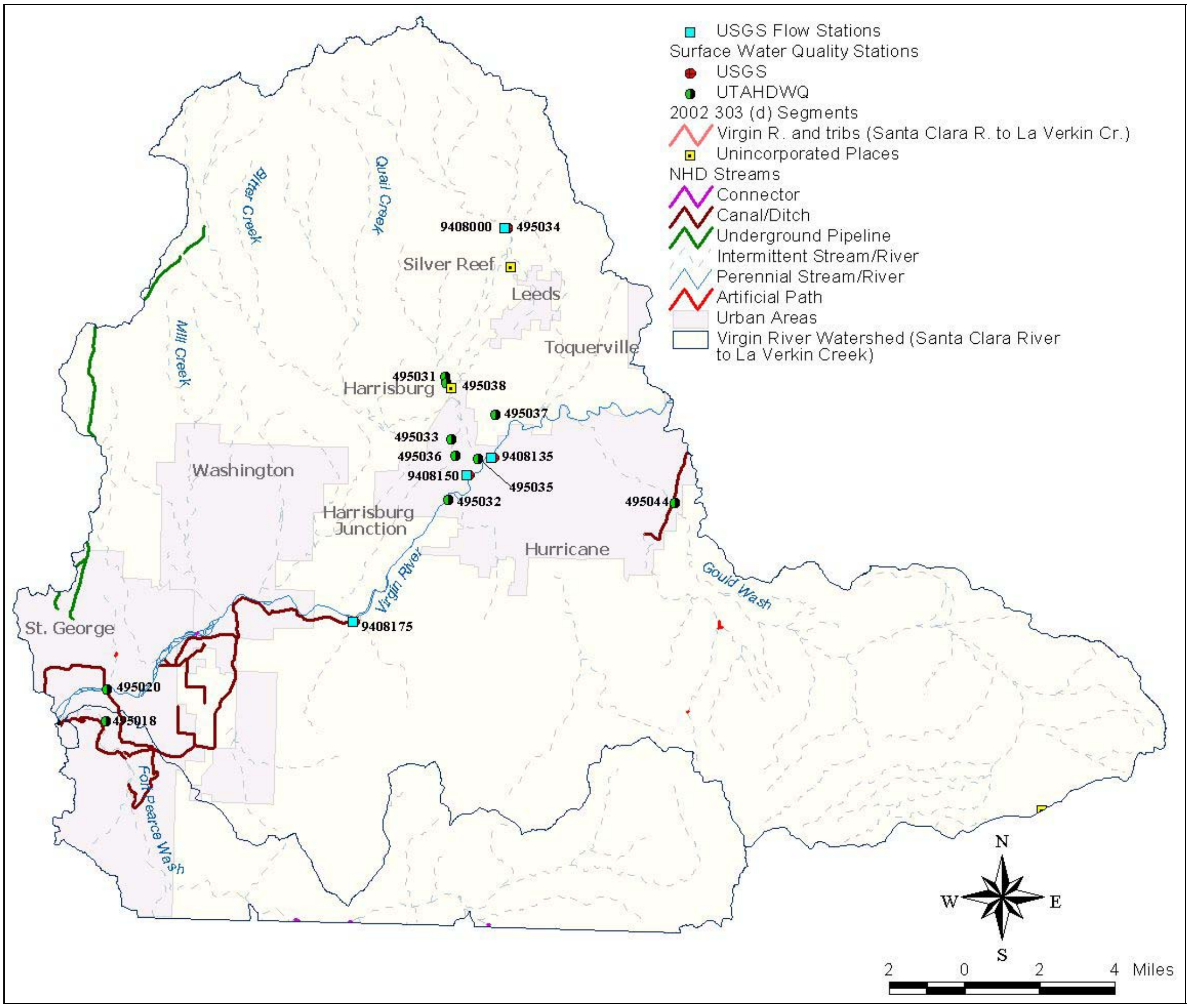


Figure 5-18. DWQ and USGS sampling stations in the Virgin River watershed between the Santa Clara River and the Quail Creek Diversion.

Table 5-19. Summary of all TDS data for the Virgin River and its tributaries from Santa Clara River confluence to the Quail Creek Diversion.

Stream Segment/ Station ID/Name	Total # of Samples	Average (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV[1]	First Sample	Last Sample
Fort Pearce Wash							
495018/ Fort Pearce Wash above Virgin River	18	1583	662	2334	31%	04/02/96	06/05/97
Leeds Creek							
495031/ Leeds Creek above Quail Creek	22	309	36	866	69%	07/09/96	06/12/02
495034/ Leeds Creek at USGS boundary	21	190	148	218	7%	01/28/86	06/06/97
Mill Creek							
599464/ Mill Creek above Johnson/Robinson Diversion	33	625	0	1818	48%	08/06/98	10/22/01
Virgin River							
495013/ Virgin River above Santa Clara River	14	1388	272	3560	71%	02/08/77	06/16/99
495032/ Virgin River at Highway 9 Crossing west of Hurricane, UT	147	1470	362	2964	38%	02/24/82	06/12/02
495020/ Virgin River southeast of St. George at CR Crossing	85	1955	498	4072	47%	01/21/75	06/12/02

[1]CV=Coefficient of variation (standard deviation/mean).

Table 5-20. Summary of TDS exceedances for the Virgin River and its tributaries from Santa Clara River confluence to Quail Creek Diversion.

Stream Segment/ Station ID/Name	Total # of Samples	Total # of Exceedances	Percent Exceeding	Total # of Samples, 1998 to Present	Total # of Exceedances, 1998 to Present	Percent Exceeding, 1998 to Present
Fort Pierce Wash						
495018/ Fort Pearce Wash above Virgin River	18	14	78%	0	NA	NA
Leeds Creek						
495031/ Leeds Creek above Quail Creek	22	0	0%	12	0	0%
495034/ Leeds Creek at USGS boundary	21	0	0%	0	NA	NA
Mill Creek						
599464/ Mill Creek above Johnson/Robinson Diversion	33	1	3%	33	1	3%
Virgin River						
495013/ Virgin River above Santa Clara River	14	7	50%	1	0	0%
495032/ Virgin River at Highway 9 Crossing west of Hurricane, UT	147	97	66%	29	21	72%
495020/ Virgin River southeast of St. George at CR Crossing	85	68	80%	10	10	100%

TDS data for the Virgin River and its tributaries between the Santa Clara River and La Verkin Creek are shown graphically in Figure 5-19 to Figure 5-26. No apparent long-term trend in TDS concentrations can be observed at any station except Leeds Creek, where a potential decrease in TDS can be observed. TDS concentrations at most stations typically increase during the spring and early summer and peak in the late summer during low flow conditions.

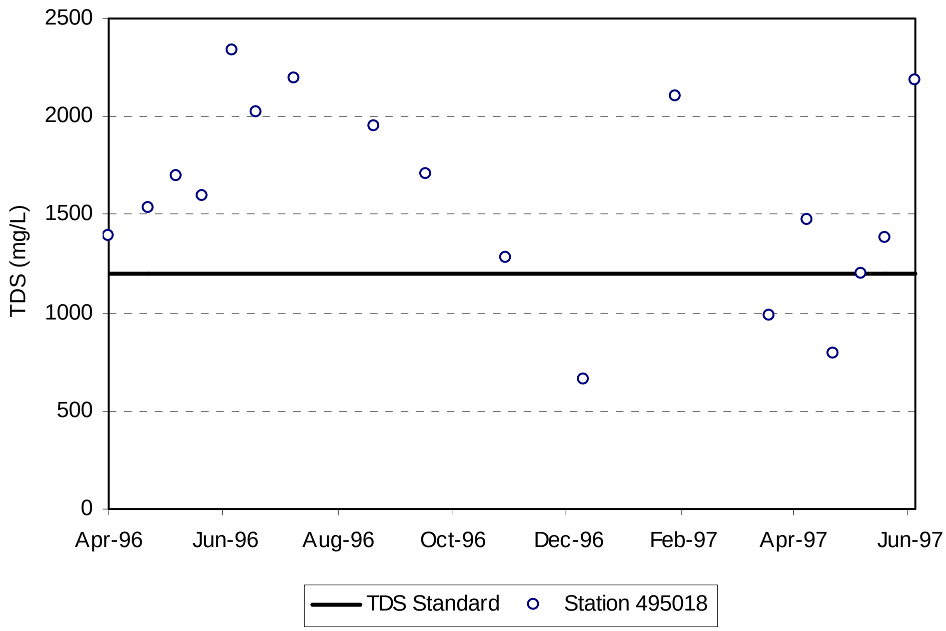


Figure 5-19. All TDS observations for Fort Pierce Wash above the confluence with the Virgin River (Station 495018).

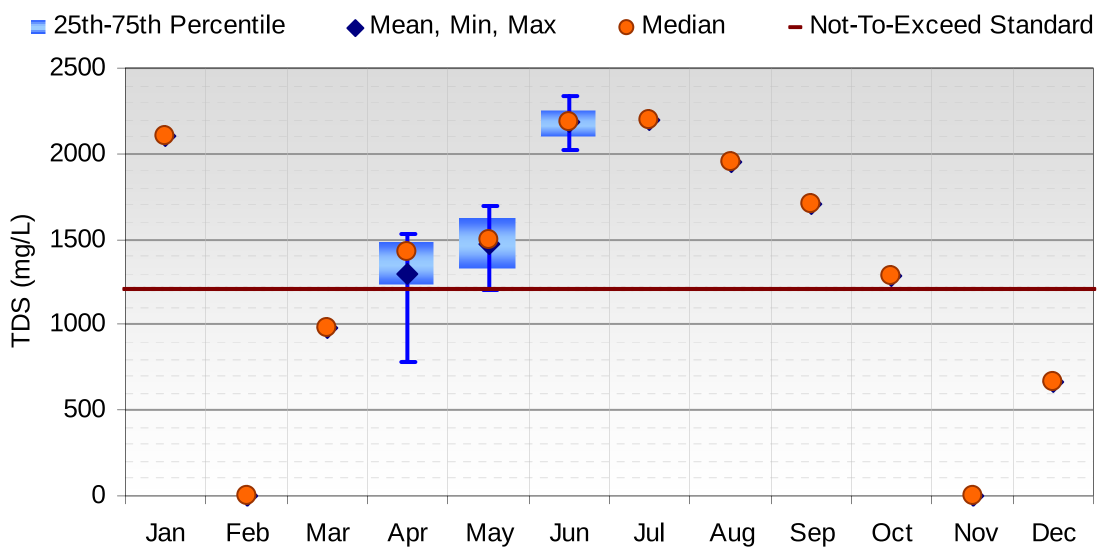


Figure 5-20. Average monthly TDS observations for Fort Pierce Wash above the confluence with the Virgin River at station 495018 (1996 to 1997).

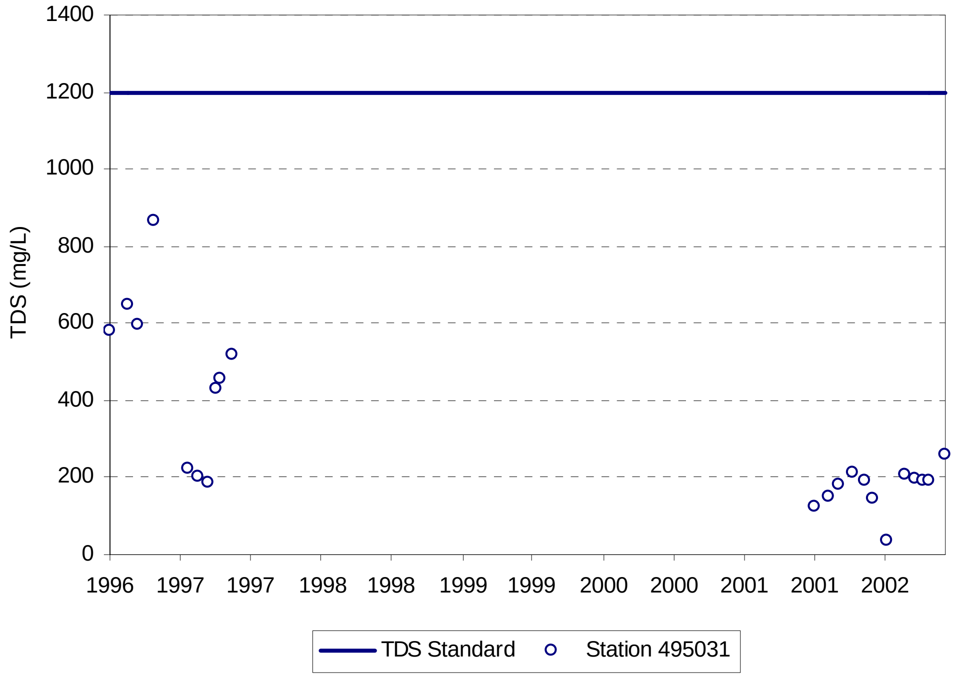


Figure 5-21. All TDS observations for Leeds Creek above Quail Creek (Station 495031).

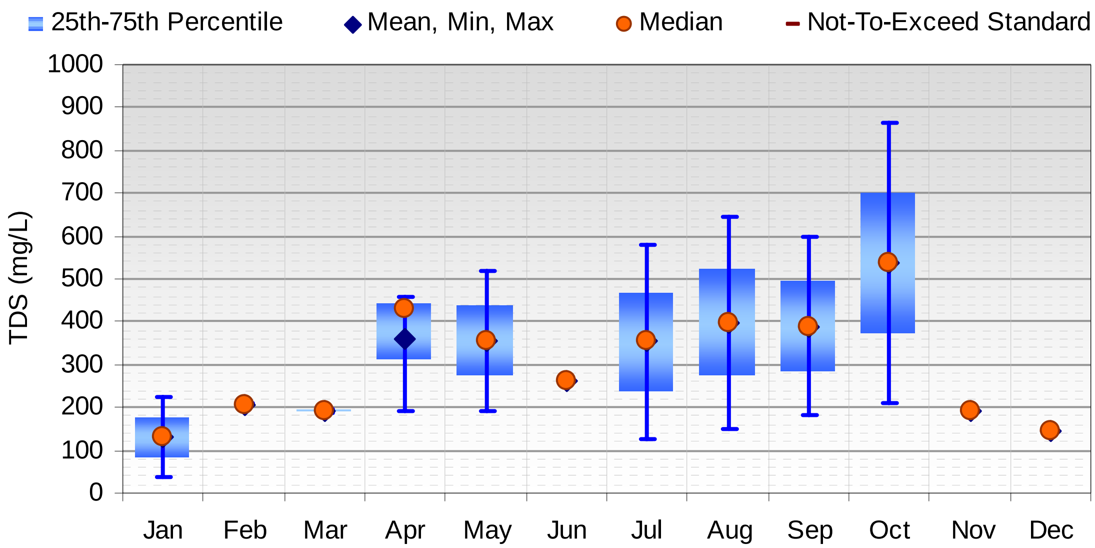


Figure 5-22. Average monthly TDS concentrations for Leeds Creek above Quail Creek at station 495031 (1996 to 2002).

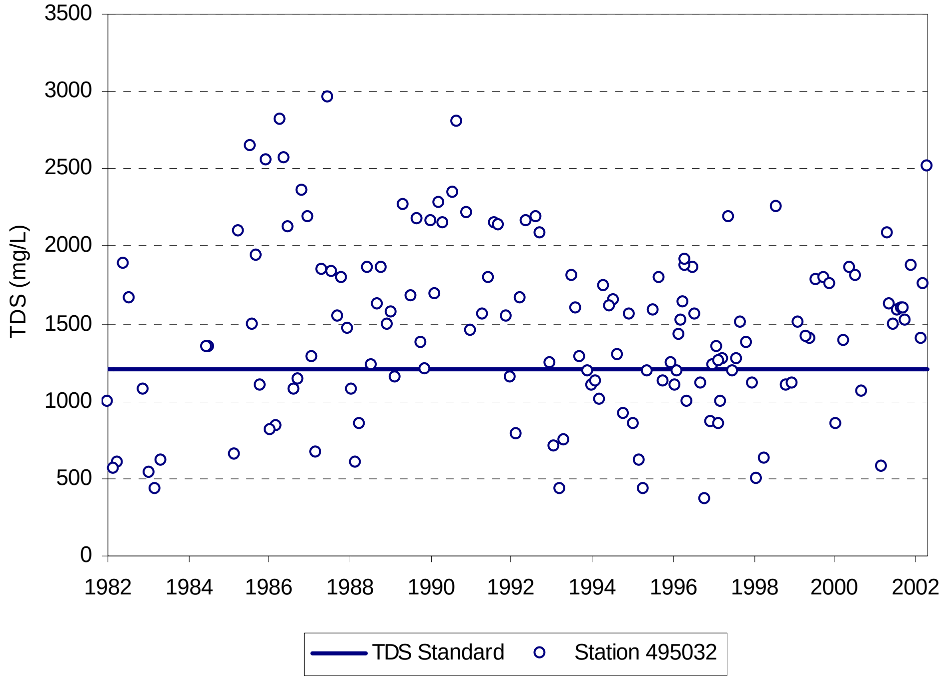


Figure 5-23. All TDS observations for the Virgin River at Highway 9 Crossing West of Hurricane (station 495032).

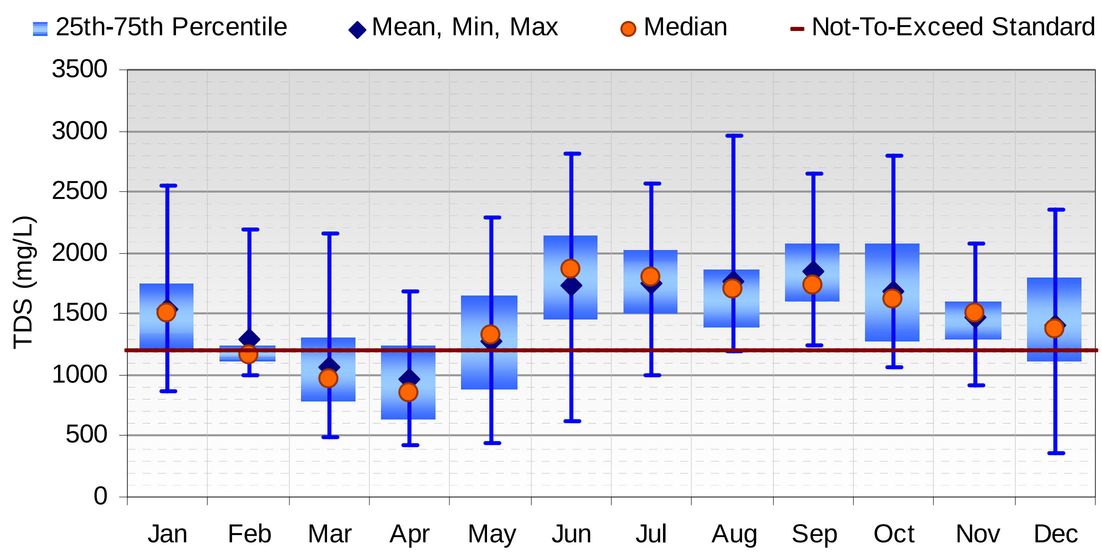


Figure 5-24. Average monthly TDS concentrations for the Virgin River at Highway 9 Crossing west of Hurricane at station 495032 (1982 to 2002).

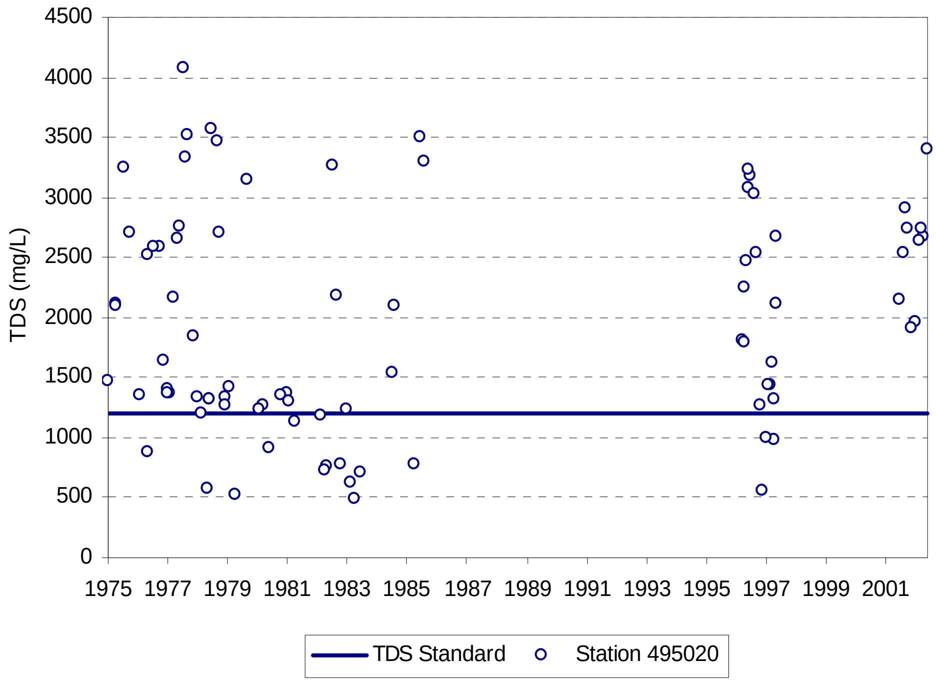


Figure 5-25. **All TDS observations for Virgin River southeast of St. George (station 495020).**

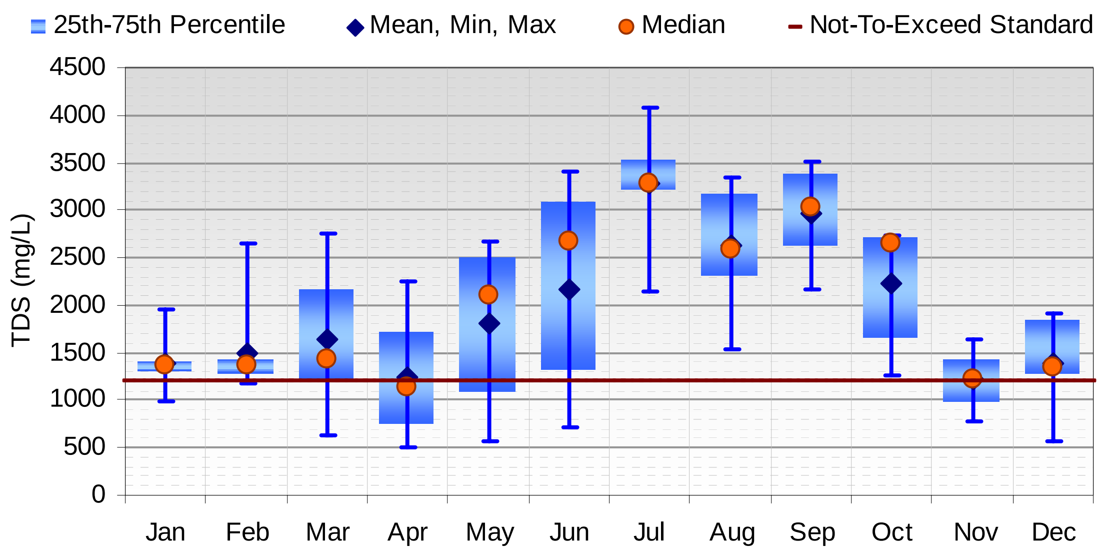


Figure 5-26. **Average TDS concentrations for the Virgin River southeast of St. George at station 495020 (1975 to 2002).**

Data from USGS gage 9413500 (Virgin River near St. George) and DWQ Station 495002 (Virgin River below first narrows) were used to evaluate TDS conditions in the segment of the Virgin River between the Arizona state line and the confluence with the Santa Clara River. Daily flow records for USGS gage 9413500 (Virgin River near St. George, UT) are available from October 15, 1950 to December 31, 1956 and October 1, 1991 to September 30, 2000. Utah DWQ collected samples at Station 495002 (Virgin River below first narrows) between August 1, 1984 to May 1, 2002. For the period of DWQ sampling where corresponding daily USGS flow is not available (August 1, 1984 to October 1, 1991), paired instantaneous flow values were used to calculate measured load. A total of 129 temporally paired TDS samples and flows are available for analysis.

Figure 5-27 and Table 5-21 present the results of the load duration analysis. They indicate that TDS loads are above the loading capacity for all but the highest flow percentiles. The most significant reduction is needed for the 30th to 40th flow percentile range.

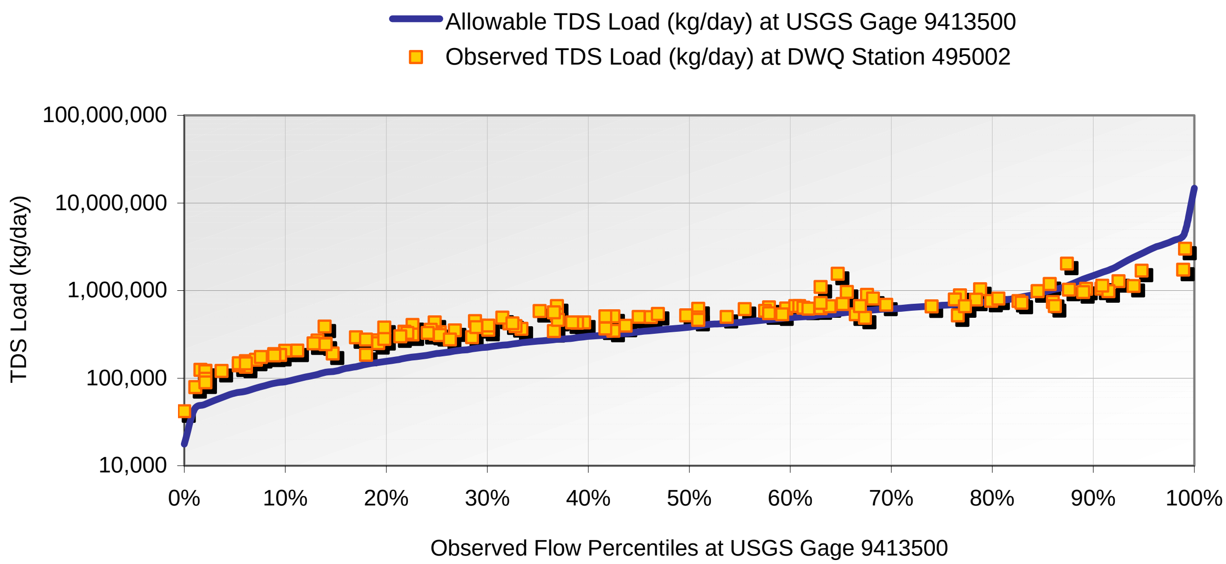


Figure 5-27. Existing TDS loading and loading capacity at station 495002 on the Virgin River below first narrows.

Table 5-21. TDS loading statistics at station 495002 on the Virgin River below first narrows using 1,200 mg/L as the TMDL target.

Flow Percentile Ranges	129-Sample Distribution	Median Observed Flow (cfs)	Observed Concentration (mg/L)	Allowable Load (kg/day)	Observed Load (kg/day)	Estimated Reduction (kg/day)	Estimated Reduction (%)
0-10	18	23.00	2,437	67,525	137,073	69,548	50.7%
10-20	15	41.00	2,503	120,372	250,882	130,510	52.0%
20-30	16	65.00	2,089	190,833	332,039	141,207	42.5%
30-40	16	90.00	1,956	264,230	430,354	166,124	38.6%
40-50	8	115.00	1,774	337,627	498,710	161,083	32.3%
50-60	11	148.00	1,520	434,512	550,054	115,542	21.0%
60-70	17	188.00	1,449	551,947	666,300	114,353	17.2%
70-80	7	231.00	1,397	678,191	788,776	110,585	14.0%
80-90	13	325.00	1,207	954,164	958,862	4,697	0.5%
90-100	8	923.60	534	2,711,589	1,206,964	0	0.0%

Data from USGS gage 9408150 (Virgin River near Hurricane) and DWQ Station 495032 (Virgin River at Highway 9 Crossing west of Hurricane) were used to evaluate conditions in the segment of the Virgin River between the confluence with the Santa Clara River and the Quail Creek Diversion. Daily flow records for USGS gage 9408150 (Virgin River near Hurricane) are available from March 1, 1967 to

September 30, 2000. Utah DWQ collected samples at Station 495032 (Virgin River at Highway 9 Crossing west of Hurricane) between February 24, 1982 and June 12, 2002. A total of 122 temporally paired Utah DWQ TDS samples and USGS flows are available for analysis.

The results of the load duration analysis are presented in Figure 5-28 and Table 5-22 and indicate that TDS loads above the loading capacity occur from the zero to the 60th flow percentiles. The largest reduction is needed for the 0 to 10th flow percentile.

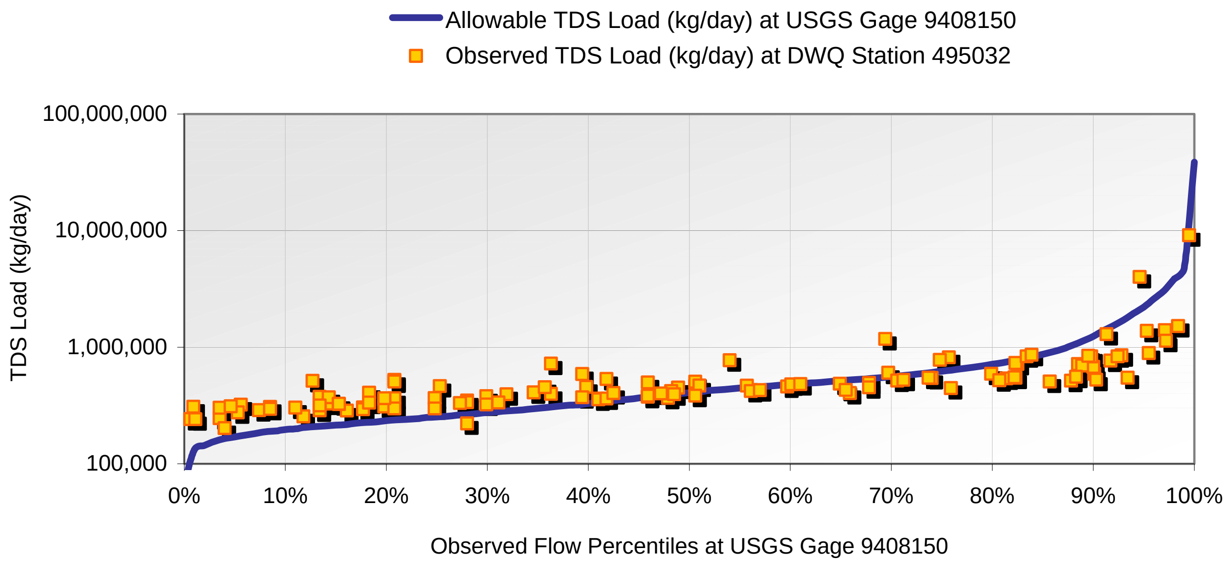


Figure 5-28. Existing TDS loading and loading capacity at station 495032 (Virgin River at Highway 9 Crossing west of Hurricane) on the Virgin River between the Santa Clara River and the Quail Creek Pipeline Diversion.

Table 5-22. TDS loading statistics at station 495032 (Virgin River at Highway 9 Crossing west of Hurricane) on the Virgin River between the Santa Clara River and the Quail Creek Pipeline Diversion.

Flow Percentile Ranges	129-Sample Distribution	Median Observed Flow (cfs)	Observed Concentration (mg/L)	Allowable Load (kg/day)	Observed Load (kg/day)	Estimated Reduction (kg/day)	Estimated Reduction (%)
0-10	12	58.00	2,062	170,282	292,478	122,197	41.8%
10-20	16	73.00	1,826	214,320	325,884	111,564	34.2%
20-30	14	86.00	1,670	252,487	351,262	98,776	28.1%
30-40	10	102.00	1,590	299,461	396,539	97,078	24.5%
40-50	14	125.00	1,303	366,986	398,146	31,160	7.8%
50-60	8	152.00	1,259	446,255	467,864	21,608	4.6%
60-70	9	176.00	1,115	516,717	479,881	0	0.0%
70-80	8	212.00	1,053	622,409	545,733	0	0.0%
80-90	16	297.00	888	871,960	644,619	0	0.0%
90-100	15	754.00	483	2,213,662	890,862	0	0.0%

Based on a review of the available data it is believed that the statewide 1,200 mg/L TDS standard as applied to the Virgin River below Pah Tempe Springs is not achievable. This conclusion is reached based on several considerations.

- TDS concentrations in streams vary depending on factors such as geology, soils, flow, precipitation, and anthropogenic practices. Concentrations can be naturally high in areas with arid conditions or where geology is easily weatherable, such as is the case with large portions of the Virgin River drainage.
- The purpose of the 1,200 mg/L standard is to protect agricultural uses. The irrigators in the watershed have adapted to the naturally high salinity of the Virgin River and, in fact, would likely not be able to implement certain best management practices that could reduce TDS loads. For example, irrigators in the Washington Fields area must flood irrigate to leach salts from the soil profile and therefore would have trouble adjusting to sprinkler irrigation.
- The “Pah Tempe” or La Verkin Springs are a natural contributor of salts and other minerals into this segment of the Virgin River. The springs issue from both banks of the river and the bottom of the river along a 2,000-foot stretch downstream of the Quail Creek Diversion. During low flow spring water is visible emerging from fissures and joints on the south bank and in the riverbed. A review of all available TDS data indicates that almost all average values at stations below Pah Tempe Springs are above the 1200 mg/l statewide standard, whereas average concentrations above the springs are below the standard (Figure 5-29).
- The impact of Pah Tempe Springs is further underscored based on the findings of a study conducted by the U.S. Department of the Interior in 1973 (USDI, 1973). USDI sampled sites above and below the entrance of the spring’s discharge into the Virgin River. They found that average salinity above the springs was 493 mg/l and ranged from 390 to 588 mg/l while average salinity below the springs was 1,153 mg/l ranged from 1,357 to 8,622 mg/l. The salinity concentrations varied widely with discharge. During low flow, concentrations of salinity were much higher than in peak flows. Based on the U.S. Department of the Interior study the average load of TDS contributed by Pah Tempe Springs is 100 million kilograms per year. This is approximately 60 percent of the total loading in this segment of the river.

The Pah Tempe Hot Springs bubble up directly into the Virgin River, contributing significant loads of TDS and other dissolved chemicals.

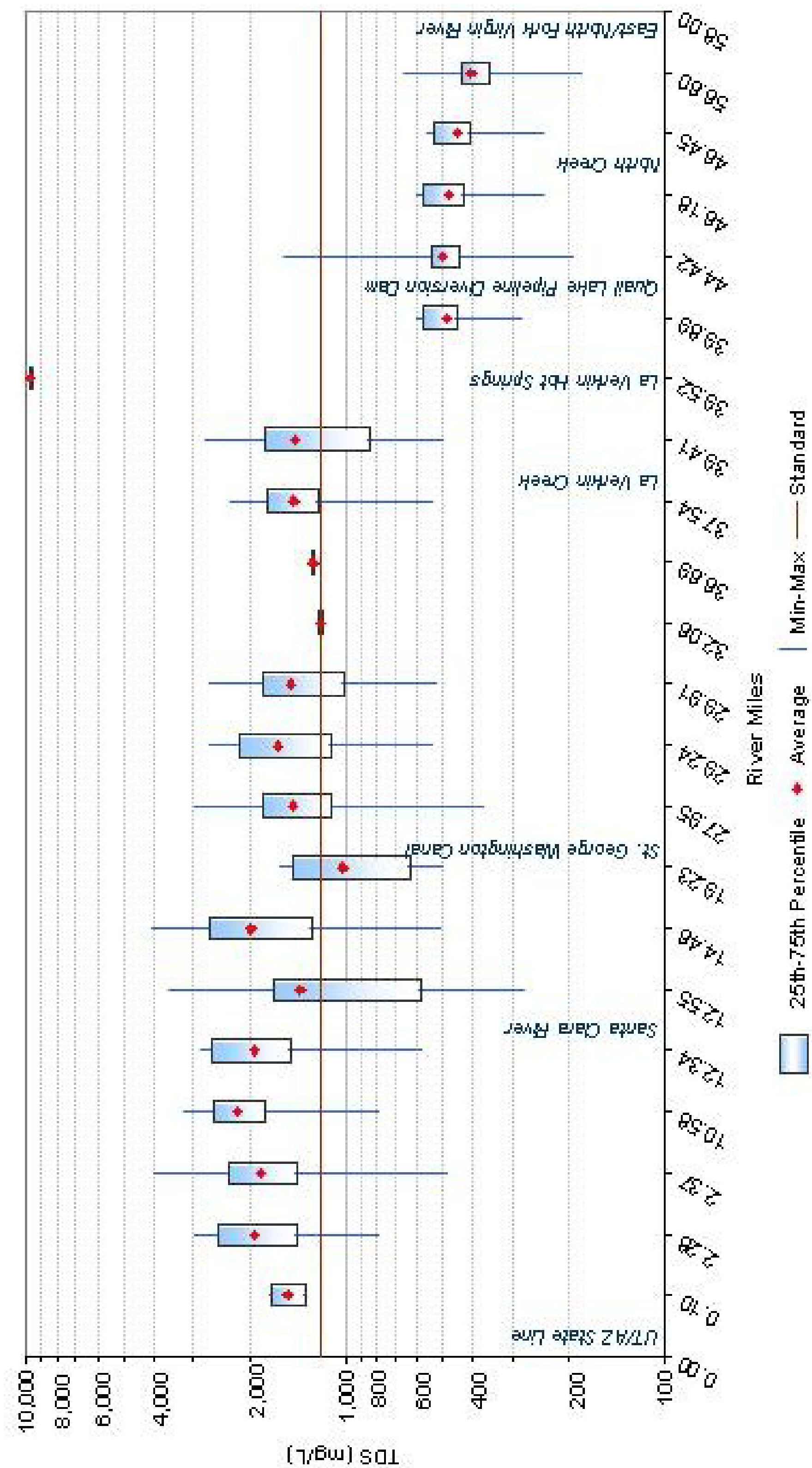


Figure 5-29. Spatial variability of TDS concentrations in the Virgin River.

Based on the considerations described above a site-specific criterion is recommended for the Virgin River from the Utah/Arizona state line to Pah Tempe Springs. EPA has published limited guidance on the adoption of site-specific criteria. The most current document is EPA's 1994 Interim Guidance on determination and use of water effect ratios for metals (USEPA, 1994). This document discusses both water effect ratio (toxicity testing) and recalculation (species sensitivity) approaches approved by EPA to modifying a criterion for a site. However, it does not include any guidance on deriving site-specific criteria for TDS or for the protection of agricultural uses. EPA provides for a flexible approach in these situations and recognizes that the methodology that is most appropriate will vary with the type of chemical, toxicology, and designated use.

Previous site-specific criteria adoptions in Utah have been based on the natural background concentration of water quality parameters where natural background is defined as background concentrations due only to non-anthropogenic sources. The natural background concentration of TDS in the Virgin River below Pah Tempe Springs was estimated by taking the following steps:

1. The average TDS concentration in the Virgin River above the Quail Creek Diversion (497 mg/L) was multiplied by the estimated flow[1] in the Virgin River below the Quail Creek Diversion (45 cfs). This resulted in an annual load of approximately 20 million kg/yr of TDS. The TDS concentration above the Quail Creek Diversion is considered representative of natural conditions because anthropogenic activities have limited impact on TDS in this segment of the Virgin River.
2. The average TDS concentration of the Pah Tempe Springs (9,650 mg/L) was multiplied by the estimated flow (11.5 cfs; USDI, 1973). This resulted in an annual load of approximately 100,000,000 kg/yr of TDS.
3. The combined load of the Virgin River below the Quail Creek Diversion and Pah Tempe Springs was divided by the combined flow to result in an average concentration of 2,360 mg/L.

A TDS concentration of 2,360 mg/L is therefore considered to represent natural background conditions and is proposed as the site-specific criterion for the Virgin River below Pah Tempe Springs to the Utah/Arizona border. (Note that the proposed site-specific criterion implicitly reflects the impact of the Quail Creek Diversion. If streamflows in the Virgin River were not diverted at the Quail Creek Diversion, the “natural” concentration would be considerably lower.)

The TDS concentrations at Hurricane and below the first narrows are summarized in Table 5-23. The data indicate that the 90th percentile of all available data at Hurricane is 2,187 mg/L, somewhat below the proposed site-specific criterion. The 90th percentile of all available data below the first narrows is 2,648, indicating that some load reductions are necessary to meet the proposed site-specific criterion.

[1] No flow gage is located on the Virgin River directly below the Quail Creek diversion. Therefore the flow was estimated by subtracting the flow of La Verkin Creek and the Pah Tempe Hot Springs from the gage on the Virgin River near Hurricane.

Table 5-23. TDS summary statistics for the Virgin River.

Statistic	TDS (mg/L) at Hurricane	TDS (mg/L) below First Narrows
Number	146	143
Mean	1470	1848
Median	1492	1844
Minimum	362	472
Maximum	2964	3990
95th Percentile	2358	2856
90th Percentile	2187	2648
85th Percentile	2130	2502
75th Percentile	1840	2347
Existing Criteria	1,200	1,200

The load duration analysis for the Virgin River below Pah Tempe Springs were re-run using 2,360 as the TMDL target. As Table 5-24 and Table 5-25 indicate no load reductions are necessary for the upstream segment of the Virgin River. Load reductions are necessary for the area downstream of the Santa Clara River, however.

Table 5-24. TDS loading statistics at station 495032 (Virgin River at Highway 9 Crossing west of Hurricane) using 2,360 as the TMDL target.

Flow Percentile Ranges	122-Sample Distribution	Median Observed Flow (cfs)	Observed Concentration (mg/L)	Allowable Load (kg/day)	Observed Load (kg/day)	Estimated Reduction (kg/day)	Estimated Reduction (%)
0-10	12	58.00	2,062	334,887	292,478	0	0.0%
10-20	16	73.00	1,826	421,496	325,884	0	0.0%
20-30	14	86.00	1,670	496,557	351,262	0	0.0%
30-40	10	102.00	1,590	588,940	396,539	0	0.0%
40-50	14	125.00	1,303	721,740	398,146	0	0.0%
50-60	8	152.00	1,259	877,636	467,864	0	0.0%
60-70	9	176.00	1,115	1,016,210	479,881	0	0.0%
70-80	8	212.00	1,053	1,224,071	545,733	0	0.0%
80-90	16	297.00	888	1,714,854	644,619	0	0.0%
90-100	15	754.00	483	4,353,534	890,862	0	0.0%

Table 5-25. TDS loading statistics at station 495002 (Virgin River below first narrows) using 2,360 mg/L as the TMDL target.

Flow Percentile Ranges	76-Sample Distribution	Median Observed Flow (cfs)	Observed Concentration (mg/L)	Allowable Load (kg/day)	Observed Load (kg/day)	Estimated Reduction (kg/day)	Estimated Reduction (%)
0-10	0	0.00	No Data	0	No Data	No Data	No Data
10-20	8	22.00	2,667	127,026	143,448	16,421	11.4%
20-30	7	42.00	2,422	242,505	248,758	6,253	2.5%
30-40	12	67.85	1,977	391,760	327,959	0	0.0%
40-50	7	94.00	1,840	542,748	422,944	0	0.0%
50-60	5	120.00	1,731	692,870	507,782	0	0.0%
60-70	8	149.00	1,549	860,314	564,493	0	0.0%
70-80	7	193.00	1,398	1,114,366	659,900	0	0.0%
80-90	11	259.00	1,201	1,495,445	760,812	0	0.0%
90-100	11	795.90	582	4,595,462	1,133,117	0	0.0%

Sources of TDS in the Virgin River downstream of the diversion include natural streambank and hillslope erosion, urban dry weather and wet weather loads, irrigation return flows, the St. George wastewater treatment plant, Fort Pierce Wash, and the Santa Clara River. Table 5-26 summarizes the relative magnitude of each of these source categories. The methodology used to estimate these loads was described above. The key assumptions used to derive the estimated loads for the Santa Clara River are listed below:

- Average flow in the Virgin River of 25 cfs and 1,825 mg/L TDS below the Washington Fields Diversion
- Concentration of 4,639 mg/L TDS in stormwater flows from St. George (based on DWQ sampling)
- Average flow of 10.8 cfs (7 million gallons per day) and 1,050 mg/L TDS from the St. George wastewater treatment plant (based on discharge monitoring reports)
- Average flow of 9 cfs and 1,582 mg/L TDS from Fort Pierce Wash
- Load from Santa Clara River based on the load duration analysis (see Section 5.3.1)
- 4500 acres of irrigated lands in the Washington Fields and other agricultural areas
- 40 inches of water applied per year
- 50 percent efficiency for irrigation
- 50 percent of unconsumed irrigated water returned to the river

Table 5-26. Sources of TDS in the Lower Virgin River.

Source Category	Load (kg/yr)	Percent
Streambank Erosion/Land Erosion/Natural Geoglogy	94,467,840	54%
Upstream	40,718,890	23%
Fort Pierce Wash	12,706,970	7%
St. George WWTP	10,149,280	6%
Santa Clara River	8,110,340	5%
Urban Dryweather and Stormwater	4,014,510	2%
Irrigation Return Flows	3,482,110	2%
Total	173,649,940	100%

The TDS TMDL for the Lower Virgin River is summarized in Table 5-27. The WLA is based on a permit limit of 20,087 tons/year of TDS for the St. George wastewater treatment plant, which is based on the design flow of the plant and the 1,200 mg/L standard.

The critical condition for the load reductions is during the summer months (June, July, and August) when existing concentrations are highest and water is needed for irrigation. The activities that should be implemented to achieve the necessary load reductions are discussed below.

Table 5-27. Summary of the TDS TMDL for the Virgin River between the Arizona/Utah state line and the Washington Fields Diversion.

Expressed as Endpoints						
• 2,360 mg/L instream TDS target			• 1,200 mg/L TDS in Santa Clara River (see TMDL above)			
Expressed as Loads						
Existing Load (kg/yr)	**Loading Capacity (kg/yr)**	**WLA (kg/yr)**	**LA (kg/yr)**	**MOS (kg/yr)**	**Reduction (kg/yr)**	**Reduction (Percent)**
173,649,940	172,814,410	18,222,620	145,951,070	8,640,720	9,476,250	5%

5.5 Kanab Creek and Tributaries from Reservoir Canyon to Headwaters

Kanab Creek and its tributaries are listed for temperature from Reservoir Canyon to the headwaters. However, there was an error associated with the original listing and therefore DWQ is in the process of petitioning USEPA to have this segment removed from the list. No TMDL will be developed for Kanab Creek.

5.6 Baker Dam Reservoir

Baker Dam Reservoir is located in the uppermost reaches of the Santa Clara River and is listed as impaired for dissolved oxygen, total phosphorus, and temperature. These listings are associated with the trophic state of the reservoir. Trophic state is a classification system limnologists have been using to describe lakes and reservoirs since the early part of the 20th century. A eutrophic (“well-nourished”) reservoir has high nutrients and high plant growth. An oligotrophic reservoir has low nutrient concentrations and low plant growth. Mesotrophic reservoirs fall somewhere in between.

Four main factors regulate trophic state:

- Availability of sunlight
- Climate
- Shape of the lake or reservoir
- Rate of nutrient supply

Of these factors, sunlight availability and the rate of nutrient supply are the two that are most temporally sensitive. Sunlight availability varies throughout the year and is one of the reasons algae concentrations are typically at their highest during the summer. When nutrient loading is too high and sunlight is available, plant growth can be excessive and impair the aquatic life, recreational, and water supply uses of a reservoir. For example, excessive algae can be aesthetically unattractive and can deplete dissolved oxygen concentrations through the processes of respiration and decomposition. High growths of attached plants can also tangle boat propellers and be a nuisance to swimmers. The following sections of this report provide information on the degree of eutrophication in Baker Dam Reservoir.

Table 5-28, Table 5-29, and Table 5-30 summarize the available dissolved oxygen data for the reservoir. Use support classifications are presented according to the DWQ guidelines described previously. The data are shown graphically in Figure 5-30. Dissolved oxygen concentrations are highest at the surface of the reservoir and decrease with depth. The reservoir appeared to be stratified during the July 25, 2000, and July 16, 2002 sampling events and during both of those events dissolved oxygen concentrations were less than 2 mg/L at the lowest depths of the reservoir. This data suggests that the reservoir is fully supporting for all sampling events because greater than 50 percent of the samples were greater than 4.0 mg/L. However, recent low water levels are probably not giving a true indication of the full range of dissolved oxygen concentrations.

Aerial view of Baker Dam Reservoir.

Ground-level view of Baker Dam Reservoir.

Table 5-28. All dissolved oxygen data for Baker Dam Reservoir.

Station ID/Name	Total # of Samples	Average (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV[1]	First Sample	Last Sample
595054/Baker Dam Reservoir above dam	115	6.9	0.1	18.1	43%	8/2/90	10/8/02
595055/Baker Dam Reservoir midlake	29	7.8	4.2	8.92	16%	6/25/98	10/8/02

[1]CV=Coefficient of variation (standard deviation/mean).

Table 5-29. Summary of dissolved oxygen exceedances for Baker Dam Reservoir station 595054.

Date of Sampling	Number of Samples	Number of Samples < 4.0 mg/L	Percent of Samples < 4.0 mg/L	Support Status
8/2/1990	3	0	0%	Fully Supporting
8/28/1990	4	0	0%	Fully Supporting
5/20/1992	13	1	8%	Fully Supporting
9/9/1992	9	0	0%	Fully Supporting
6/15/1994	13	5	38%	Fully Supporting
8/16/1994	7	1	14%	Fully Supporting
6/25/1998	14	3	21%	Fully Supporting
6/6/2000	15	0	0%	Fully Supporting
7/25/2000	9	4	44%	Fully Supporting
5/29/2002	8	0	0%	Fully Supporting
7/16/2002	6	2	33%	Fully Supporting
8/7/2002	6	0	0%	Fully Supporting
10/8/2002	8	0	0%	Fully Supporting

Table 5-30. Summary of dissolved oxygen exceedances for Baker Dam Reservoir station 595055.

Date of Sampling	Number of Samples	Number of Samples < 4.0 mg/L	Percent of Samples < 4.0 mg/L	Support Status
6/25/1998	13	0	0%	Fully Supporting
6/6/2000	9	0	0%	Fully Supporting
5/29/2002	3	0	0%	Fully Supporting
10/8/2002	4	0	0%	Fully Supporting

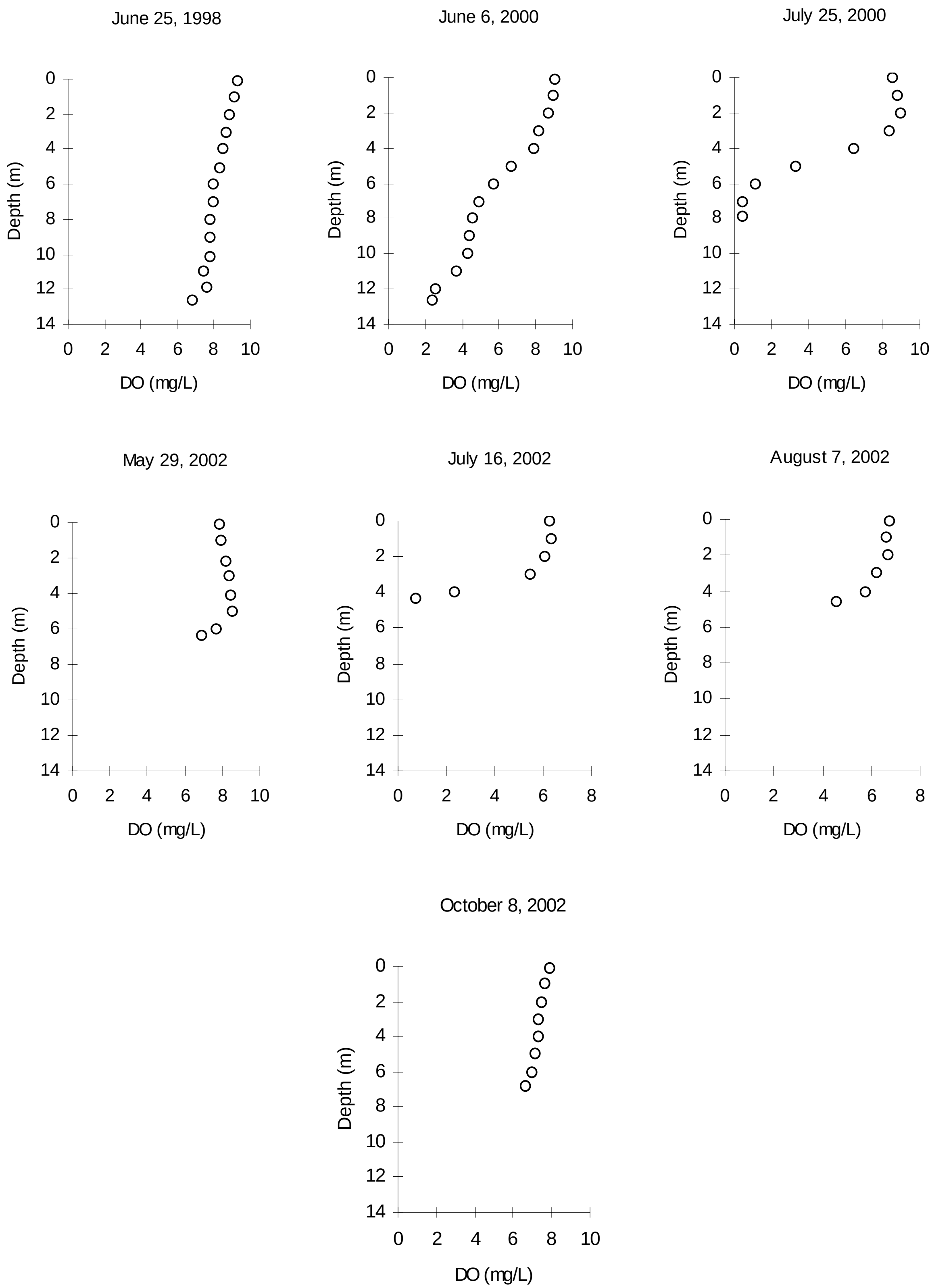


Figure 5-30. Dissolved oxygen data for Baker Dam Reservoir above the dam at station 595054.

Table 5-31 summarizes the available temperature data for the reservoir. Use support classifications are presented according to the DWQ guidelines described previously. The data indicate that the reservoir did not fully support uses during 7 of 12 sampling events because more than 10 percent of the temperature samples were warmer than 20 ºC. The data are shown graphically in Figure 5-2. Temperatures are highest at the surface of the reservoir and decrease with depth. Stratification of the reservoir only appears to occur when the depth is greater than 8 meters. Average reservoir temperatures have therefore likely been warmer than normal during the past several years due to the drought conditions.

Table 5-31. Summary of temperature exceedances for Baker Dam Reservoir station 595054.

Date of Sampling	Number of Samples	Number of Samples > 20 ºC	Percent of Samples > 20 ºC	Support Status	Maximum Reservoir Depth (m)	Ambient Monthly Air Temp (20 ºC)	Upstream Santa Clara Temp (20 ºC)
8/2/1990	3	3	100%	Not Supporting	1.5	26.3	23.2
8/28/1990	4	0	0%	Fully Supporting	3	26.3	21.1
5/20/1992	14	0	0%	Fully Supporting	13	18.9	12
9/9/1992	9	3	33%	Not Supporting	7.2	22	17.9
6/15/1994	13	0	0%	Fully Supporting	12	24.2	19.3
8/16/1994	7	7	100%	Not Supporting	5.6	26.3	22
6/25/1998	14	0	0%	Fully Supporting	12.6	24.2	15.8
6/6/2000	13	3	23%	Not Supporting	12.6	24.2	22.1
7/25/2000	9	8	89%	Not Supporting	7.9	27.4	23.6
7/16/2002	6	6	100%	Not Supporting	4.3	27.4	22.2
8/7/2002	6	6	100%	Not Supporting	4.6	26.3	16.9
10/8/2002	8	0	0%	Fully Supporting	6.8	15.8	10.6

A multiple regression analysis was run to determine the influence of reservoir depth, ambient air temperatures, and upstream Santa Clara River temperatures on temperature conditions in Baker Dam Reservoir. In multiple regression, two or more independent predictor variables are analyzed to determine their relationship to a dependant variable. The result is an equation that best predicts the dependant variable. In the case of Baker Dam Reservoir, air temperature, tributary temperature, and the maximum depth of the reservoir were regressed against the dependant variable average reservoir temperature. The resulting equation is shown below.

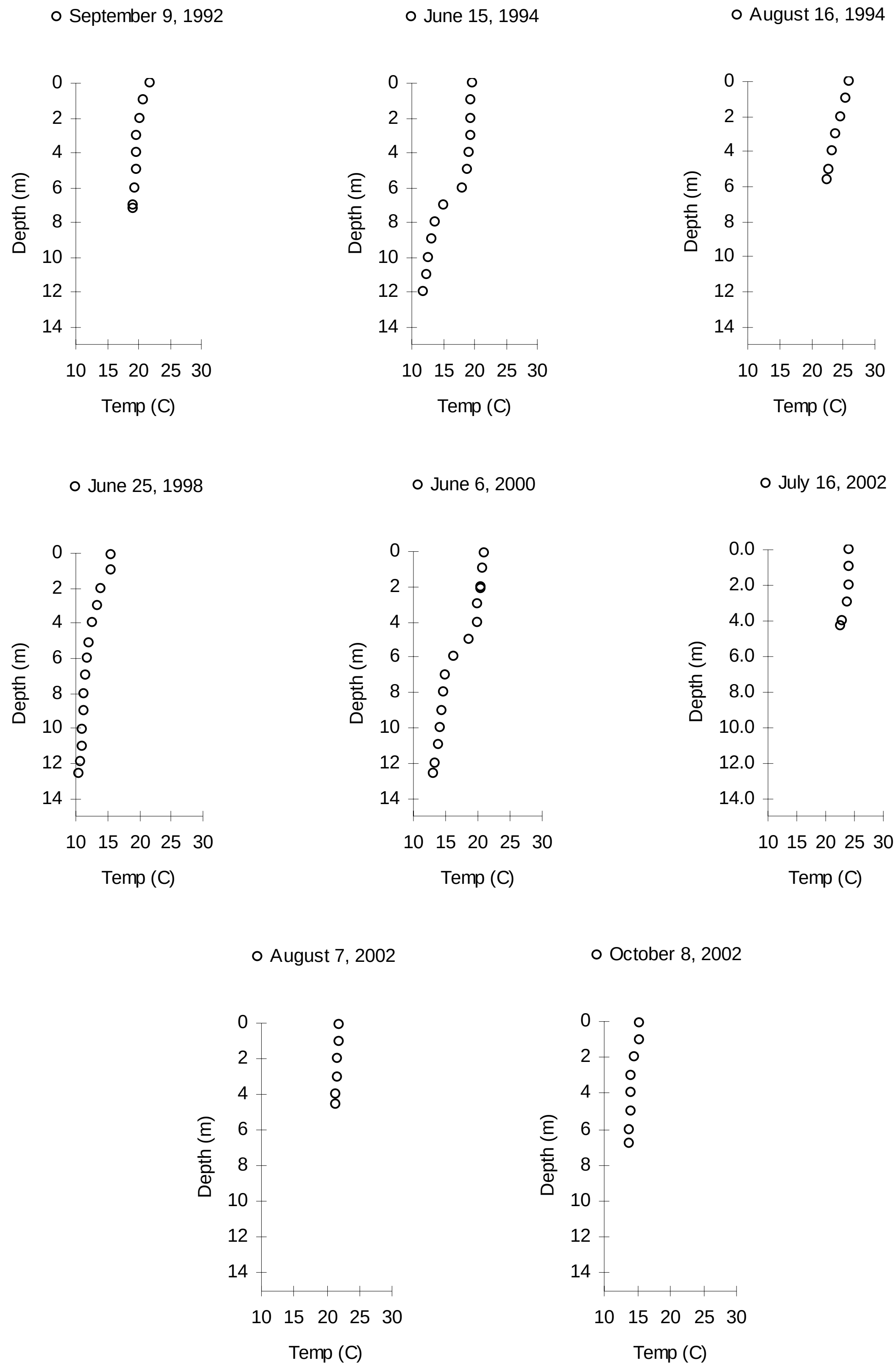


Figure 5-31. Temperature data for Baker Dam Reservoir above the dam at station 595054.

$$ReservoirTemp = (TribTemp * 0.435) - (MaxDepth * 0.441) + (AirTemp * 0.072) + 12.19$$

The R^2 value for this equation was 0.62, meaning that approximately 62 percent of the variability in the reservoir temperature data is explained by the variables equation. The coefficients on the predictor variables indicate that tributary temperatures and reservoir depth have the greatest effect on reservoir temperature. For example, average reservoir temperature is predicted to decrease by 0.44 ºC both for every additional one meter of reservoir depth or for every 1 ºC decrease in tributary temperatures. In this way the equation can be used to determine what conditions are necessary to meet the temperature standard. The equation indicates that tributary temperatures should be reduced from a current average of 21.5 ºC to 20 ºC and reservoir depth should be maintained at 4 meters or deeper to keep average reservoir temperatures below 20 ºC during the critical months of July and August.

Total phosphorus data for Baker Dam Reservoir are summarized in Table 5-32 and Table 5-33 and the data are shown graphically in Figure 5-32 and Figure 5-33. Average concentrations exceed DWQ's recommended pollution indicator value of 0.025 mg/L and more than sixty percent of the samples since 1998 have exceeded the indicator value. There does not appear to be any long-term trend in concentrations and monthly concentrations are quite variable.

Figure 5-34 graphically presents the proportion of total dissolved phosphorus to total phosphorus as a monthly average at station 595054 (Baker Dam Reservoir above the dam). The dissolved portion of total phosphorus ranges from approximately 30 percent in September to approximately 90 percent in May. The monthly proportion of total dissolved phosphorus to total phosphorus is greater than 65 percent in May, June, and August. Total dissolved phosphorus was not sampled in July.

Table 5-32. Summary of all total phosphorus data for Baker Dam Reservoir.

Station ID/Name	Total # of Samples	Average (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV[1]	First Sample	Last Sample
595054/Baker Dam Reservoir above dam	40	0.090	0.020	0.450	127%	6/3/1981	5/29/2002
595055/Baker Dam Reservoir midlake	24	0.060	0.010	0.200	92%	9/2/1980	5/29/2002

[1]CV=Coefficient of variation (standard deviation/mean).

Table 5-33. Summary of total phosphorus exceedances for Baker Dam Reservoir.

Station ID/Name	Total # of Samples	Total # of Exceedances	Percent Exceeding	Total # of Samples, 1998 to Present	Total # of Exceedances, 1998 to Present	Percent Exceeding, 1998 to Present
595054/Baker Dam Reservoir above dam	40	32	80%	12	10	83%
595055/Baker Dam Reservoir midlake	24	17	71%	6	4	66%

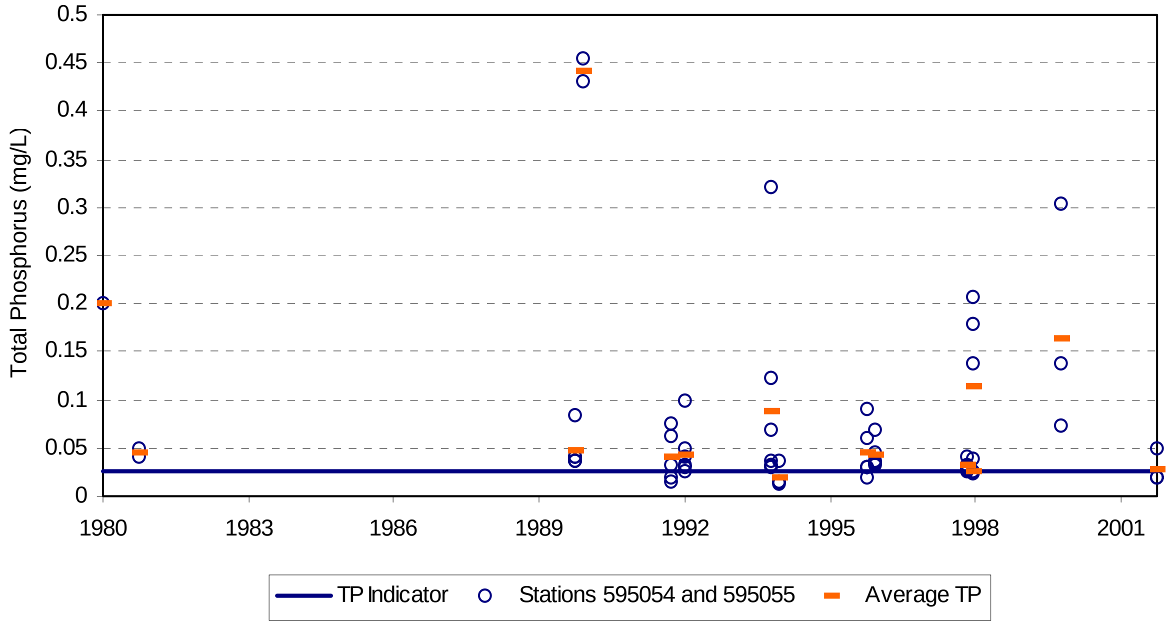


Figure 5-32. All total phosphorus data for Baker Dam Reservoir above the dam and midlake (Stations 595054 and 595055). Data taken at different depths were averaged to determine one value for the sampling date.

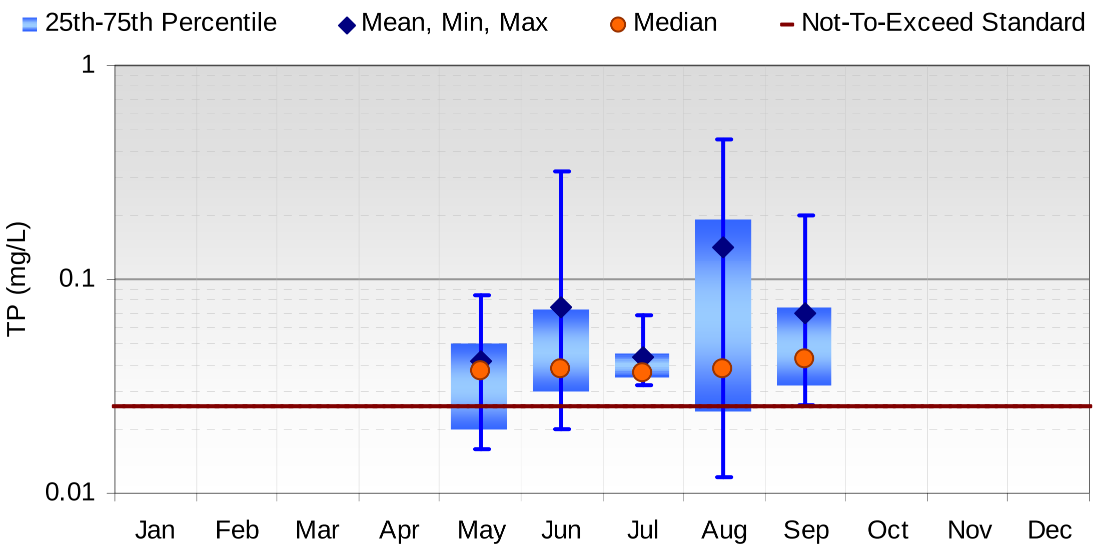


Figure 5-33. Average monthly total phosphorus concentrations for Baker Dam Reservoir above the dam at station 595054 (1981 to 2002).

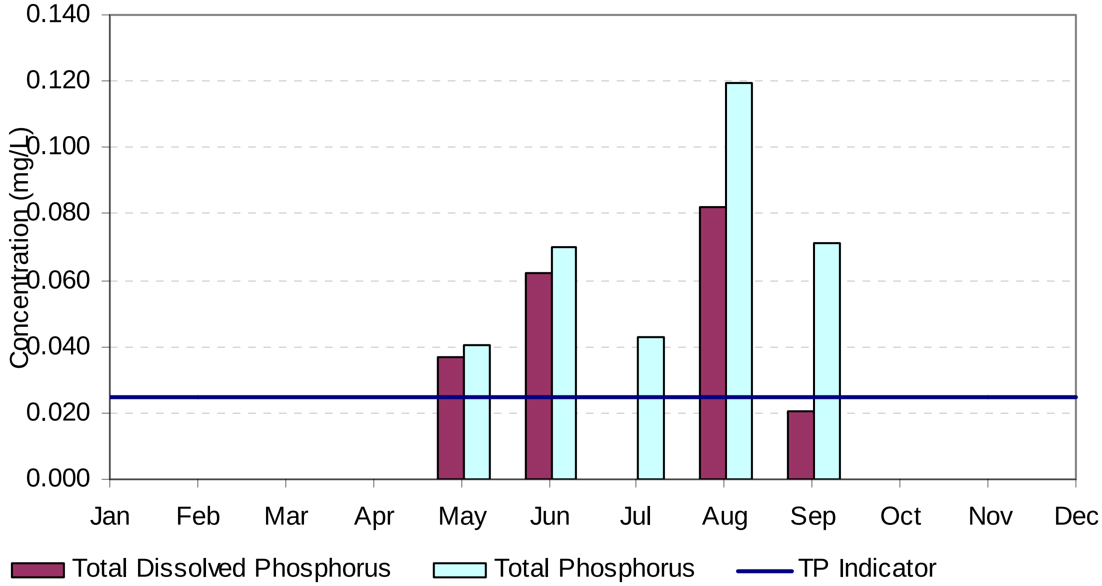


Figure 5-34. Average monthly proportion of total dissolved phosphorus to total phosphorus at station 595054 (Baker Dam Reservoir above the dam).

TP data can also be used to determine the eutrophic status of a reservoir using the classification system developed by Carlson (1977). Table 5-34 displays the TSI classification for Baker Dam Reservoir using the available TP data. There do not appear to be any improving or worsening trends over time.

Table 5-34. TSI classifications for Baker Dam Reservoir based on TP.

Date	TP at station 595054 (mg/L)	TP at station 595055 (mg/L)	TSI Score
9/2/1980	No Data	0.20	81
6/3/1981	0.05	0.04	59
5/30/1990	0.05	0.04	59
8/1/1990	0.44	No Data	92
5/20/1992	0.04	0.05	59
9/9/1992	0.05	0.03	57
6/15/1994	0.13	0.05	69
8/16/1994	0.03	0.01	47
6/12/1996	0.05	0.05	61
7/31/1996	0.05	0.04	59
6/25/1998	0.03	0.03	53
8/18/1998	0.03	No Data	53
8/19/1998	0.13	0.10	73
6/6/2000	0.19	0.14	78
5/29/2002	0.04	0.02	53

The Carlson classification system also produces a measure of eutrophication based on transparency. Table 5-35 displays the TSI classification for Baker Dam Reservoir according to secchi disk depth. Similar to the TP data, the secchi information indicates that the reservoir is typically eutrophic and conditions have not changed considerably over time.

Table 5-35. TSI classifications for Baker Dam Reservoir based on Secchi Depth.

Date	Secchi Depth (m) at station 595054	Secchi Depth (m) at station 595055	TSI Score
9/2/1980	3	3	44
5/30/1990	3.6	1.8	46
8/1/1990	0.9	No Data	62
5/20/1992	2	2	50
9/9/1992	2.4	2.2	48
6/15/1994	4	4	40
8/16/1994	1.8	1.6	52
6/12/1996	3.2	3.2	43
7/31/1996	2.5	1.8	49
6/25/1998	1.35	1.3	56

Date	Secchi Depth (m) at station 595054	Secchi Depth (m) at station 595055	TSI Score
8/18/1998	1.95	No Data	50
8/19/1998	No Data	2.3	48
6/6/2000	2.3	2.5	47
7/25/2000	2.3	2.4	48
5/29/2002	2.7	2.1	47
7/16/2002	2.95	No Data	44
8/7/2002	1.5	No Data	54

The Carlson classification system also produces a measure of eutrophication based on chlorophyll *a* and these data are shown in Table 5-36. Conditions do not appear to have significantly improved or worsened during the past 12 years.

Table 5-36. Summary of available chlorophyll a data for Baker Dam Reservoir.

Date	Chlorophyll *a* at station 595054 (μg/L)	Chlorophyll *a* at station 595055 (μg/L)	Average Chlorophyll *a* (μg/L)	TSI Score
8/1/1990	130.8	No Data	130.8	78
5/20/1992	9.7	21.1	15.4	57
9/9/1992	5.1	4.6	4.85	46
6/15/1994	4.3	3.1	3.7	43
8/16/1994	3.8	5.8	4.8	46
6/12/1996	11.6	7.1	9.35	53
7/31/1996	9.6	11.3	10.45	54
6/25/1998	6.9	8.8	7.85	51
8/18/1998	6.3	No Data	6.3	49
8/19/1998	No Data	4.5	4.5	45
6/6/2000	6.7	15.7	11.2	54
7/25/2000	4.3	3.1	3.7	43
5/29/2002	0.2	0.5	0.35	20

A summary of the algal taxa collected from Baker Dam Reservoir is presented in Table 5-37 to Table 5-40. The algal biomass for the sampled dates consisted of blue green algae, diatoms, flagellates, and green and yellow green algae. On July 31, 1996, the major groups contributing to algal biomass (94%) included the blue green algae *Aphanizomenon flosaquae* (48%) *and Anabaena spiroides crassa* (47%).

Both these algal taxa indicate eutrophic conditions and polluted waters. Flagellates included *Chlamydomona* (3%), a flagellate indicating polluted water and eutrophic conditions. Green algae comprised less than one percent of the algal sample in the reservoir at this time. Diatoms comprised (1.5%) of the sample, while flagellates comprised approximately four percent of the algal sample taken from the reservoir.

On August 19, 1998 the major group contributing to algal biomass was overwhelmingly diatoms (79%). The diatom *Fragilaria crotonensis* (52%) indicates oligotrophic conditions. *Bactillariophyta sp.* (27.3%) also dominated the algal sample. There were no blue green algae present in the algal sample taken from the reservoir at the time of sampling. Some green algae were present (16%) in the phytoplankton sample, including *Ankistrodesmus falcatus,* that indicate clean water conditions. Diatoms including *Melosira granulata angustissima* (3%), an indicator of eutrophic conditions, were identified in low amounts. Flagellates comprised only one percent of the sample.

Algal taxa were collected from Baker Dam reservoir in both August and October 2002. On August 8, 2002 the major group contributing to algal biomass was diatoms (59%). However, blue-green algae were the second most dominant group. By October 8, 2002, a blue-green species (*Microcystis Aeruginosa*) had become the dominant species although diatoms still composed a majority of the sample (39%).

Table 5-37. Algal Taxa Present Collected from Baker Dam Reservoir Reservoir, July 31, 1996.

Taxon	Rank	Relative Density %	Mean Number per liter	Cell Volume (mm^3/l)
Blue Green Algae				
Aphanizomenon flosaquae	1	47.56	1,089760	20.705
Anabaena spiroides crassa	2	46.49	289,120	20.2384
Green and Yellow Green Algae				
Oocystis	9	0.06	16,680	0.0278
Sphaerocystis schroeteri	13	0.02	5560	0.00834
Chloropyta sp.1	6	0.25	27,800	0.10898
Staurastrum gracile	7	0.08	22,240	0.03336
Ankyra judai	10	0.06	16,680	0.02502
Diatoms				
Melosira granulata angustissima	4	1.4	55,600	0.6116
Melosira granulata	12	0.03	11,120	0.1334
Stephenodiscus niagarae	11	0.05	11,120	0.0222
Bacillariophyta sp.2	8	0.08	16,680	0.03336
Asterionella formosa	14	0.02	5,560	0.00667
Flagellates				
Phacotus	5	0.59	33,360	0.25576
Chlamydomonas sp.	3	3.32	55,600	1.4456

Table 5-38. Algal Taxa Present Collected from Baker Dam Reservoir, August 19, 1998.

Taxon	Rank	Relative Density %	Mean Number per liter	Cell Volume (mm^3/l)
Green and Yellow Green Algae				
Oocystis sp.1	11	0.3	5,500	0.03022
Oocystis gigas	12	0.3	5,500	0.0242
Sphaerocystis schroeteri	8	0.6	22,000	0.0561
Chloropyta sp.1	13	0.1	5,500	0.00825
Ankistrodesmus falcatus	5	2	38,500	0.1771
Schroederia setigera	7	0.9	27,500	0.077
Pediastrum duplex	3	11.2	44,000	0.97821
Cosmarium sp.	14	0.1	5,500	0.0055
Diatoms				
Melosira granulata angustissima	4	3.1	38,500	0.275
Bacillariophyta sp.2	2	27.3	66,000	2.39642
Asterionella formosa	6	1.4	33,000	0.1221
Fragilaria crotonensis	1	51.7	110,000	4.532
Flagellates				
Euglena sp.1	9	0.6	16,500	0.0528
Dinobryon divergens	10	0.4	11,000	0.033
Chlamydomonas sp.	15	0	5,500	0.0022

Table 5-39. Algal Taxa Present Collected from Baker Dam Reservoir, August 8, 2002.

Taxon	Rank	Relative Density %	Mean Number per liter	Cell Volume (mm3/l)
Blue Green Algae				
Aphanizomenon Flos-Aquae	2	11.7	3,100	0.01878
Microcystis Incerta	8	1.4	15,700	0.007199
Oscillatoria Species	10	0.5	3,100	0.002504
Unknown Spherical Cyanophyta	6	3.7	18,800	0.01878
Green and Yellow Green Algae				
Oocystis Gigas	6	3.7	3,100	0.01878
Pteromonas Species	8	1.4	15,700	0.007199
Tetraedron Species	10	0.5	3,100	0.002504
Unknown Spherical Chlorophyta	6	3.7	18,800	0.01878
Diatoms				
Centric Diatoms	11	0.4	3,100	0.002191
Melosira Granulata Var Angustissima	4	5.7	6,300	0.028796
Pennate Diatoms	5	3.9	25,000	0.020032
Stephanodiscus Niagarae	1	59.1	9,400	0.30048

Table 5-40. Algal Taxa Present Collected from Baker Dam Reservoir, October 8, 2002.

Taxon	Rank	Relative Density %	Mean Number per liter	Cell Volume (mm3/l)
Blue Green Algae				
Microcystis Aeruginosa	1	34.7	1,000	0.20658
Green and Yellow Green Algae				
Ankistrodesmus Falcatus	5	0.4	5,000	0.002457
Lyngbya Birgei	2	26.3	2,000	0.1565
Diatoms				
Melosira Granulata Var Angustissima	3	21.8	3,000	0.129582
Stephanodiscus Niagarae	4	16.8	4,000	0.10016

Table 5-41 and Figure 5-36 indicate that the average TSI score for Baker Dam Reservoir is 54 with values typically ranging between 45 and 55. A slight improvement in conditions can be noted from the sampling done in 1990 to the latest data for 2002. However, there is no consistent trend and conditions as recent as 2000 indicate high chlorophyll concentrations and low transparency. The entire period of record indicates a reservoir that is eutrophic, which agrees with the conclusions drawn from looking at the TP, transparency, and algal population data. Only the dissolved oxygen data indicate a reservoir that is fully supporting its designation for cold water aquatic life, and these are based on limited data that might not have been taken during critical conditions. Therefore the recommendation of this TMDL is to reduce TP concentrations to decrease algal growth and increase dissolved oxygen concentrations. The link between TP, algal growth, and dissolved oxygen is explained below.

Algae and macrophytes (rooted and floating aquatic plants) require a variety of inorganic elements to sustain life. Two of these elements, phosphorus and nitrogen, are needed in significant concentrations to sustain the production of organic plant material. Algae and some macrophytes mostly obtain these nutrients from the water column (as opposed to from the air or soil). However, the amount of nitrogen and phosphorus an aquatic plant needs is often significantly higher than the naturally occurring concentrations found in water (Vallentyne, 1974). This phenomenon is referred to as the *Limiting Nutrient* law, because the concentration of nitrogen and phosphorus in a waterbody almost always limits algae and macrophyte growth (i.e., there simply isn't enough phosphorus or nitrogen present to further organic matter production). Therefore, increasing the amount of nitrogen and phosphorus in a waterbody tends to cause an increase in algae and macrophyte production (assuming all other variables remain the same). Given an infinite amount of nitrogen and phosphorus in the water column, production would increase until another element limited production (most likely carbon or silicon).

The ratio of nitrogen to phosphorus (N:P ratio) in biomass is approximately 7.2 (Chapra, 1997). This ratio provides an estimate to determine which nutrient is limiting production in a lake. If the ratio of nitrogen to phosphorus concentrations in a lake is greater than 7.2, it suggests that phosphorus is limiting plant growth. A nitrogen to phosphorus ratio lower than 7.2 suggests that nitrogen is limiting plant growth. Concentration data from Gunlock Reservoir and Baker Reservoir suggest that phosphorus is limiting growth (i.e., the N:P ratios are greater than 7.2). Therefore, reducing the phosphorus concentrations in the reservoirs should reduce algae and macrophyte production in the reservoirs (Sakamoto, 1966; Dillon and Rigler, 1974; Jones and Bachman, 1976; Schindler, 1978; Vollenweider, 1976; Oglesby and Schaffner, 1978; Rast and Lee, 1978; Canfield and Bachman, 1981; as reported in

Wetzel, 2001). Chlorophyll-a is a surrogate measurement for biomass, as it is found in almost all macrophytes and algae. It is easy to measure and correlates well with total biomass in a lake. The general relationship between chlorophyll-a and total phosphorus is given in the equation shown below.

$$(Chloro-a) = 0.55\left[\frac{P_i}{(1+\sqrt{t_w})}\right]^{0.76}$$

Where

Chloro-a = average annual chlorophyll-a concentration in the reservoir (mg/m^3)
P_i = average inflow concentration of total phosphorus (mg/m^3)
t_w = average residence time of water in the reservoir

Studies have shown that this relationship exists, with minor deviations, for many lakes and reservoirs throughout the United States (as reported in Wetzel, 2001). Figure 5-35 indicates that this relationship holds true for both Gunlock and Baker Dam Reservoir.

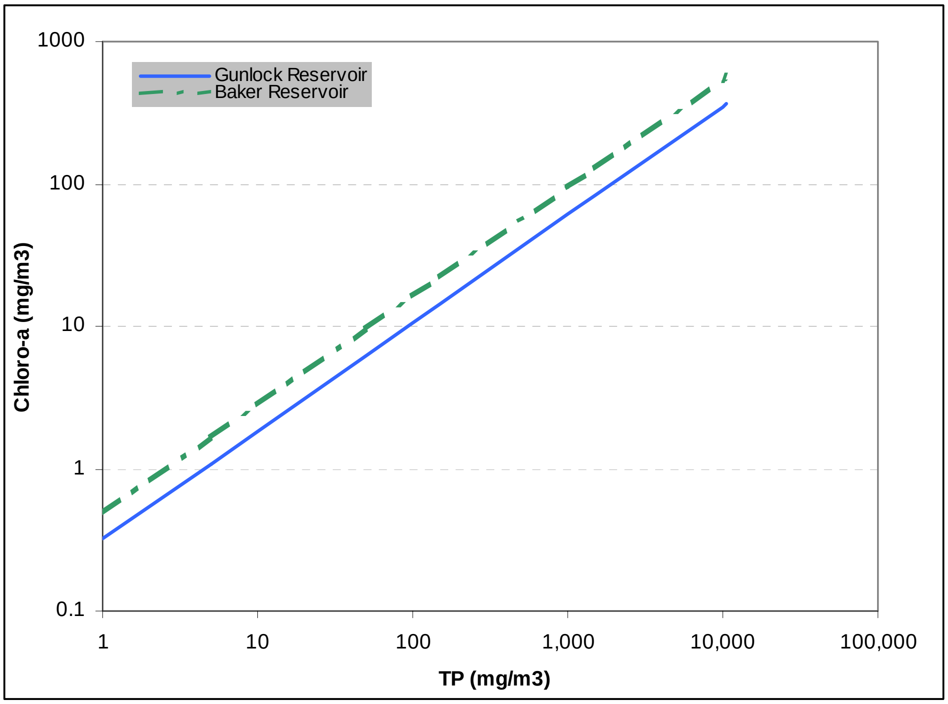


Figure 5-35. Average annual *chlorophyll-a* concentrations versus average annual total phosphorus concentrations (input).

Algae and macrophytes both produce and consume oxygen in water. During daylight hours, oxygen is produced by photosynthesis. Plants and algae then consume oxygen from the water column at night (respiration). The production and respiration cycle is represented by the following equation:

$$6CO_2 + 6H_20 \underset{respiration}{\overset{photosynthesis}{\rightleftarrows}} C_6H_{12}O_6 + 6O_2$$

The entire process is part of the natural cycle of most plants, and this cycle causes dissolved oxygen concentrations to fluctuate throughout the water column in a day. This is called a diurnal oxygen cycle. However, the oxygen balance in a reservoir is much more complicated than the previous equation. Various other processes produce and consume dissolved oxygen in the water column. Processes that consume oxygen include organic decomposition, respiration by fish and invertebrates, and sediment oxygen demand. Additional dissolved oxygen is produced through atmospheric exchange. The amount and timing of oxygen production and consumption depends on several of the following factors (Thomann and Mueller, 1987; Wetzel, 2001).

- Solar radiation and water clarity
- Air and water temperature, wind speed
- Algae and macrophyte growth and death/decay rates
- Presence or absence of essential elements
- Type of algae/macrophytes present in the water column
- Residence time of the lake
- Lake stratification
- Amount of dissolved oxygen present in the water column
- Lake depth, size, shape, and wave action

Oxygen depletion occurs when the balance between oxygen consumption and production is altered, either causing excessive oxygen consumption or reduced oxygen production. The dissolved oxygen concentration in a waterbody becomes too low, thereby threatening oxygen breathing aquatic life. Because algae and macrophytes are by far the largest producers and consumers of oxygen in a lake, a shift in that community can greatly affect the dissolved oxygen of a lake (Wetzel, 2001). However, it is difficult to accurately predict the change in dissolved oxygen concentrations due to a change in lake biomass because of the complexity of the variables and processes involved. Various equations and models have been developed to explain these processes (as summarized in Thomann and Mueller, 1987; Wetzel, 2001; Chapra, 1997). The basic processes linking excessive lake biomass to low dissolved oxygen concentrations are summarized below.

- Most algae communities have natural, seasonal succession. The timing between growth (oxygen producing) and decay (oxygen consuming) can be very different. This shift causes periods when there is excessive decomposition and little new growth, resulting in extreme oxygen depletion (especially near the lake bottom). These seasonal successions often coincide with lake stratification (thermal layering) in the lake, which can exacerbate the problem (Wetzel, 2001).
- Excessive algae and macrophytes in a lake cause the diurnal oxygen cycle to expand. Dissolved oxygen becomes extremely high during the daytime, often resulting in oxygen supersaturation. Dissolved oxygen then falls to extremely low concentrations during the night (plant respiration), causing fatal conditions for aquatic life (Thomann and Mueller, 1987).
- Natural and anthropogenic sources can cause the sudden death of algae and macrophytes. This results in a situation with excessive decay and no biological oxygen production.

In summary, the low dissolved oxygen conditions in Baker Dam Reservoir are the result of excessive algae and macrophytes coupled with the recent low water levels. Dissolved oxygen concentrations can be increased by removing algae and macrophytes from the system and, as discussed above, the most effective method for removing biomass is by reducing the total phosphorus loading. Therefore a total phosphorus TMDL has been developed addressing total phosphorus loading and reductions. The analysis described above and the results of the BATHTUB modeling described below indicate that these phosphorus reductions should result in increases to the dissolved oxygen concentrations to the point that water quality standards will be met.

Table 5-41. Summary of TSI scores for Baker Dam Reservoir for all dates for which phosphorus, secchi, and chlorophyll a data are available.

Date	TSI Score for Phosphorus	TSI Score for Secchi Depth	TSI Score for Chlorophyll a	Average TSI Score
8/1/1990	92	62	78	77
5/20/1992	59	50	57	55
9/9/1992	57	48	46	50
6/15/1994	69	40	43	51
8/16/1994	47	52	46	48
6/12/1996	61	43	53	52
7/31/1996	59	49	54	54
6/25/1998	53	56	51	53
8/18/1998	53	50	49	51
8/19/1998	73	48	45	55
6/6/2000	78	47	54	60
5/29/2002	53	47	20	40
Average	63	49	50	54

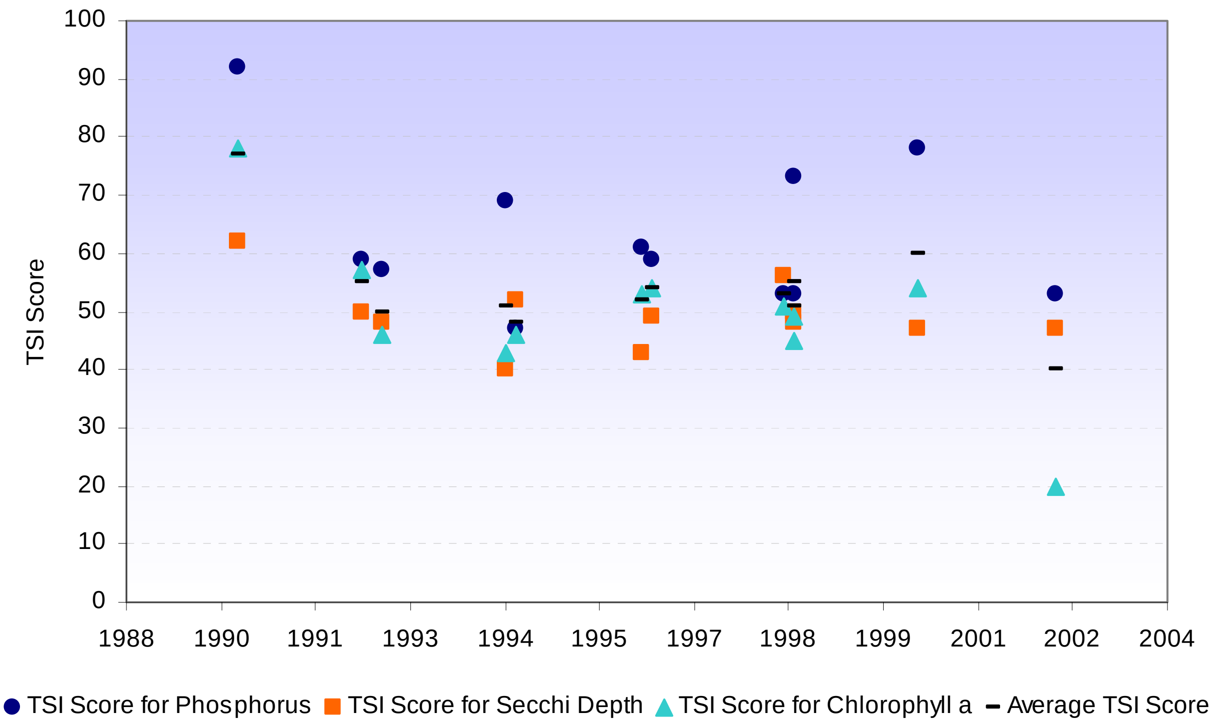


Figure 5-36. Summary of TSI scores for Baker Dam Reservoir for all dates for which phosphorus, secchi, and chlorophyll a data are available.

5.6.1 Modeling

The BATHTUB model was used to estimate the load reductions necessary to meet the TP pollution indicator value of 0.025 mg/L. TP loads to Baker Dam Reservoir were based on sampling data available above the reservoir (DWQ station 595059) and flow data from the USGS gage near Central. The average TP concentration at station 595059 is 0.07 mg/L and the average flow at the USGS gage is 8.1 cfs.

The model was first calibrated and validated to existing conditions and then used to evaluate various load reduction scenarios. Approximately a 70 percent reduction in loads was determined to be necessary to meet the 0.025 mg/L target, which is predicted to result in meeting the dissolved oxygen standards.

Table 5-42 provides the estimated TP loads from each of the significant sources in the Baker Dam Reservoir watershed. The primary sources of TP to Baker Dam Reservoir are livestock and failing septic systems. This conclusion is based on the loading estimates described below and is reinforced by the fact that a high proportion of TP is in the dissolved form. Natural sources of TP from streambank or hillslope erosion would result in high particulate and low dissolved phosphorus concentrations. The following assumptions were used to estimate the loading of TP to the reservoir:

- Approximately 500 cattle are located in the watershed above Baker Dam Reservoir. This estimate is based on observations made from the air in June 2003 and from the field in October 2003. A typical TP generation rate of 0.017 kg/day/animal was assumed based on literature values for the TP concentration of manure (0.05 kg/ P_2O_5/455 kg/animal/day) and a representative animal weight of 350 kg (NRCS, 1999). Most of the cattle were observed in the Pine Valley meadows with direct access to the Santa Clara River and therefore a relatively high transport rate (10 percent) was assumed for the delivery of phosphorus to the river.
- Approximately 500 septic systems are located above Baker Dam Reservoir in the towns of Pine Valley and Central. These values are based on previous studies of the watershed (Hansen, Allen, and Luce, 1997). Site-specific information on the proportion of these systems that are failing systems was not available. A national average of 15 percent (USEPA, 2002) was therefore selected to estimate loads from this source to Baker Dam Reservoir.
- There are only about 1,600 acres of irrigated land above the reservoir.
- Internal loading of TP is not a significant factor because of the apparent low number of days during which the lower depths of the reservoir are anoxic.

Table 5-42. Sources of TP to Baker Dam Reservoir.

Source Category	Load (kg/yr)	Percent
Livestock	320	55%
Land Erosion/Streambank Erosion	170	29%
Septic Systems	90	16%
Total	580	100%

The TP TMDL for Baker Dam Reservoir is summarized in Table 5-43. The WLA is zero because there are no point sources. The critical condition for the load reductions is during the summer months when climatic conditions are most conducive to excessive algal growth. The activities that should be implemented to achieve the necessary load reductions are discussed below.

Table 5-43. Summary of the TP and temperature TMDLs for Baker Dam Reservoir.

Expressed as Endpoints

- Reduction of in-reservoir TP concentration to 0.025
- Continued DO concentrations above 4.0 mg/L in greater than 50 percent of water column
- Shift in phytoplankton dominance from blue-green algae
- TSI values between 40 and 50
- No fish kills
- Maintain temperature in greater than 90 percent of the water column less than 20ºC by maintaining reservoir depths and reducing tributary temperatures

Expressed as Loads

Existing Load (kg/yr)	Loading Capacity (kg/yr)	WLA (kg/yr)	LA (kg/yr)	MOS (kg/yr)	Reduction (kg/yr)	Reduction (Percent)
580	175	0	166	9	414	71%

5.7 Gunlock Reservoir

Gunlock Reservoir is an intermediate size impoundment of the Santa Clara River located between Veyo and Ivins. It is a warmwater fishery known for bass and crappie fishing. Gunlock Reservoir is listed as being impaired due to low dissolved oxygen and high total phosphorus concentrations.

The Santa Clara River between Veyo and Moody/Magatsu flows through a narrow and largely inaccessible basalt canyon. Little if any human activities take place and riparian vegetation is dominated by native species. Between Moody/Magatsu and Gunlock Reservoir the Santa Clara River valley widens significantly and agricultural fields lie along one or both sides of the river. However, irrigation appears to be largely by sprinkler limiting the quantity of irrigation return flows. Riparian vegetation is largely native coyote willow, desert willow, and cottonwood. An active sand and gravel operation mines material from the channel bed upstream of the reservoir. The deep excavations and spoil piles within the channel may create stream channel stability upstream and downstream inducing channel incision or increased bank erosion that leads to elevated loads of particulate phosphorus.

Another factor affecting water quality in Gunlock Reservoir is a diversion used at a power plant in the town of Gunlock. Water from the Santa Clara River, above Baker Dam Reservoir, is diverted into an open channel diversion to supply this power plant. Because this diversion is located at a higher elevation it is possible to run it across normal divides and hillslopes and transport the water across the land to the town of Gunlock in a more direct manner. While much of this diversion is an open channel, some sections are piped. Since the water is diverted from the Santa Clara River above Baker Dam Reservoir, Veyo, Brookhaven, and Gunlock, it is not subjected to several potential sources. Therefore when the diversion rejoins the Santa Clara River downstream of the power plant, it is a higher quality water.

Table 5-44, Table 5-45, and Table 5-46 summarize available dissolved oxygen data and indicate that dissolved oxygen concentrations occasionally violate water quality standards. Figure 5-37 indicates that dissolved oxygen concentrations decrease with depth and that impairments usually occur later in the summer when the reservoir is stratified. Several of the July sampling events (e.g., July 27, 1999 and July 16, 2002) are noteworthy because of the significant number of observations of less than 1.0 mg/L dissolved oxygen.

Aerial view of Gunlock Reservoir on the Santa Clara River.

Cattle grazing at Gunlock Reservoir

Table 5-44. All dissolved oxygen data for Gunlock Reservoir.

Station ID/Name	Total # of Samples	Average (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV[1]	First Sample	Last Sample
495051/Gunlock Reservoir above the dam	233	5.4	0.0	10.77	58%	8/31/89	10/9/02
495052/Gunlock Reservoir midlake	78	6.4	0.5	12.2	35%	8/9/95	10/9/02

[1]CV=Coefficient of variation (standard deviation/mean).

Table 5-45. Summary of dissolved oxygen exceedances for Gunlock Reservoir station 495051.

Date of Sampling	Number of Samples	Number of Samples < 4.0 mg/L	Percent of Samples < 4.0 mg/L	Support Status
8/31/1989	14	5	36%	Fully Supporting
5/22/1991	20	3	15%	Fully Supporting
8/7/1991	13	5	38%	Fully Supporting
6/2/1993	24	2	8%	Fully Supporting
8/4/1993	22	15	68%	Partially Supporting
8/9/1995	12	2	17%	Fully Supporting
6/12/1997	21	10	48%	Fully Supporting
7/27/1999	23	15	65%	Partially Supporting
6/5/2001	20	0	0%	Fully Supporting
6/6/2001	22	0	0%	Fully Supporting
8/16/2001	16	8	50%	Partially Supporting
7/16/2002	15	10	67%	Partially Supporting
10/9/2002	11	0	0%	Fully Supporting

Table 5-46. Summary of dissolved oxygen exceedances for Gunlock Reservoir station 495052.

Date of Sampling	Number of Samples	Number of Samples < 4.0 mg/L	Percent of Samples < 4.0 mg/L	Support Status
8/9/1995	13	3	23%	Fully Supporting
6/12/1997	14	5	36%	Fully Supporting
7/27/1999	11	1	9%	Fully Supporting
6/5/2001	15	0	0%	Fully Supporting
8/16/2001	11	2	18%	Fully Supporting
7/16/2002	9	4	44%	Fully Supporting
10/9/2002	5	0	0%	Fully Supporting

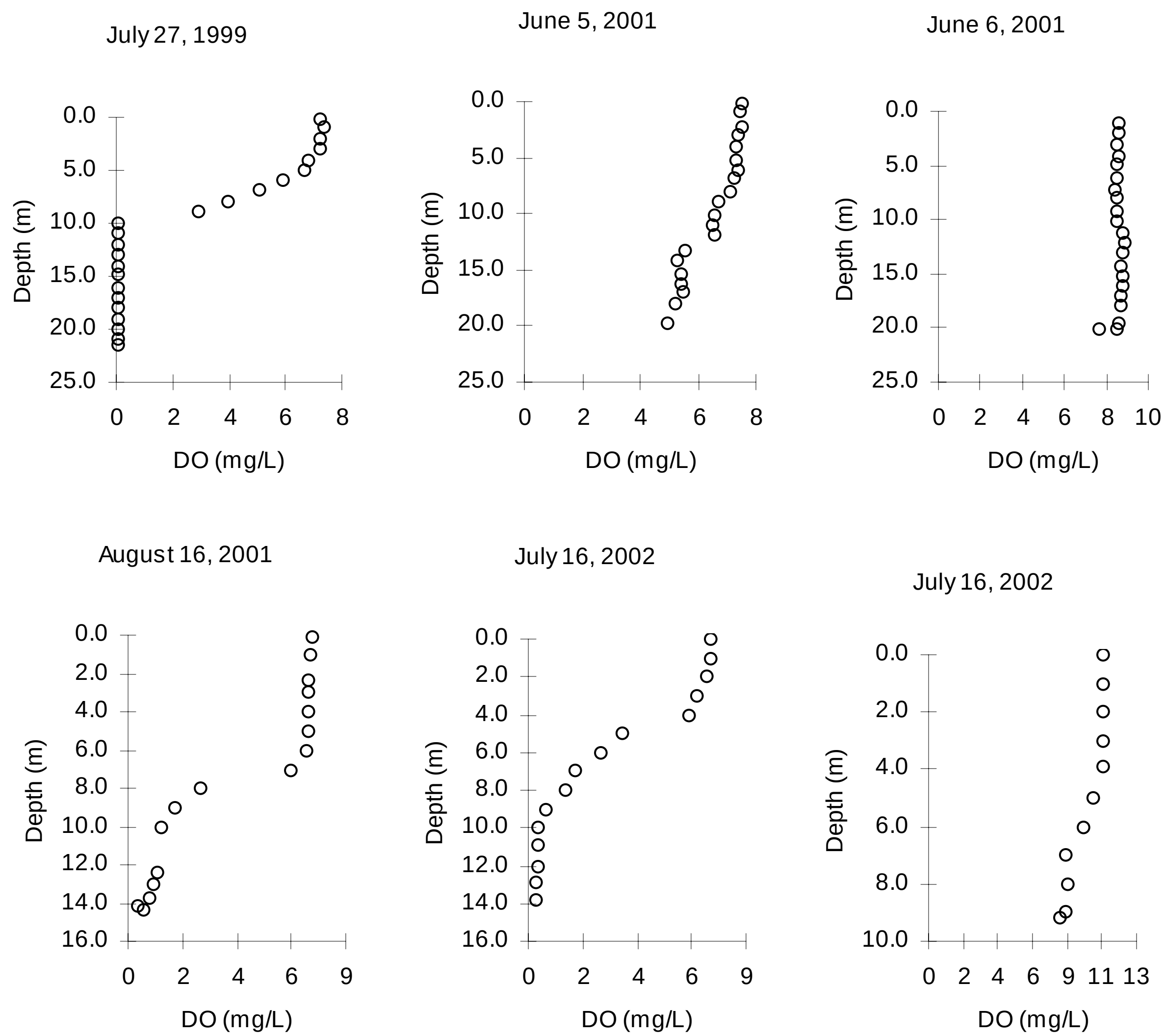


Figure 5-37. Recent dissolved oxygen data for Gunlock Reservoir above the dam at station 495051.

The total phosphorus data for Gunlock Reservoir are summarized in Table 5-47 and Table 5-48 and Figure 5-38 and Figure 5-39. Average concentrations in May and June are above the pollution indicator value of 0.025 mg/L but concentrations in August are below the pollution indicator value. Data are not available for other months. More than 40 percent of recent samples have exceeded 0.025 mg/L.

Table 5-47. Summary of all total phosphorus data for Gunlock Reservoir.

Station ID/Name	Total # of Samples	Average (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV[1]	First Sample	Last Sample
495051/Gunlock Reservoir above the dam	42	0.030	0.010	0.200	103%	5/24/79	8/16/01
495052/Gunlock Reservoir midlake	22	0.030	0.010	0.090	76%	5/24/79	8/16/01

[1]CV=Coefficient of variation (standard deviation/mean).

Table 5-48. Summary of total phosphorus exceedances for Gunlock Reservoir.

Station ID/Name	Total # of Samples	Total # of Exceedances	Percent Exceeding	Total # of Samples, 1998 to Present	Total # of Exceedances, 1998 to Present	Percent Exceeding, 1998 to Present
495051/Gunlock Reservoir above the dam	42	17	40%	9	4	44%
495052/Gunlock Reservoir midlake	22	18	82%	4	2	50%

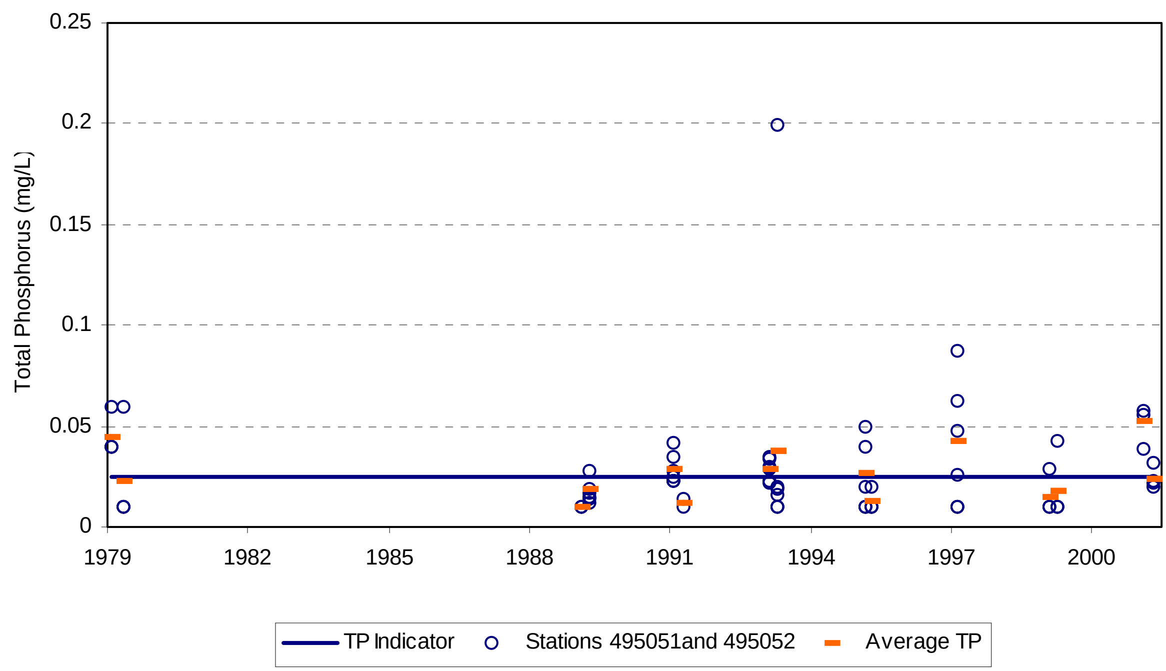


Figure 5-38. All total phosphorus data for Gunlock Reservoir above the dam and midlake (stations 495051 and 495052). Data taken at different depths were averaged to determine one value for the sampling date.

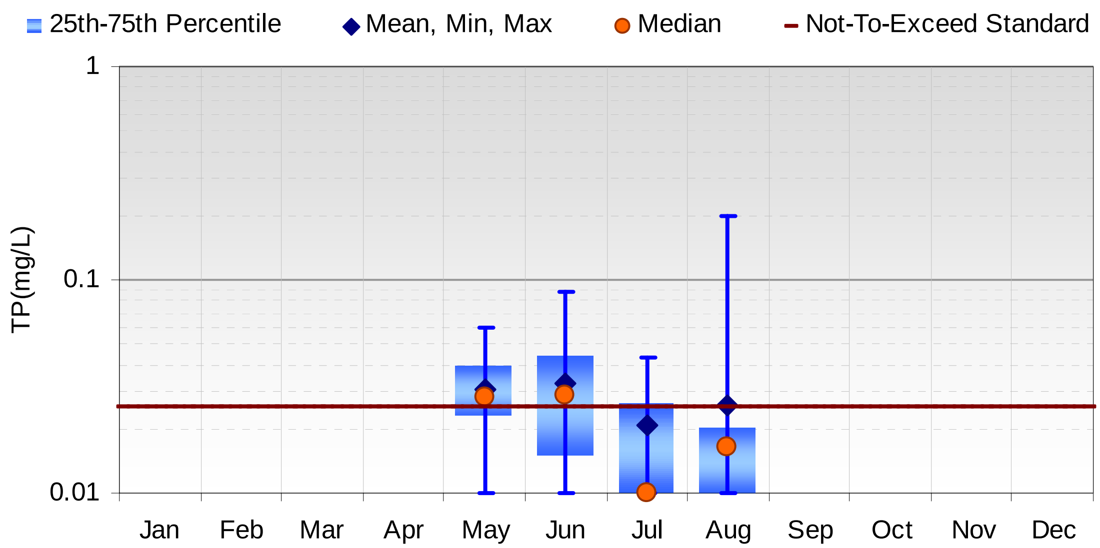


Figure 5-39. Average monthly total phosphorus concentrations for Gunlock Reservoir above the dam and midlake (stations 495051 and 495052) (1979 to 2001).

The average total dissolved phosphorus and total phosphorus concentrations for each sampling event at the station above the dam are shown in Table 5-49. Total dissolved phosphorus is often a relatively large proportion of total phosphorus, indicating the presence of sources such as septic systems and livestock.

Table 5-49. Average proportion of total dissolved phosphorus to total phosphorus at station 595054 (Gunlock Reservoir above the dam).

Date	Total Dissolved Phosphorus (mg/L)	Total Phosphorus (mg/L)	Percent Total Dissolved Phosphorus
5/31/89	0.008	0.010	80%
8/2/89	0.004	0.015	27%
5/22/91	0.010	0.030	33%
8/7/91	0.006	0.012	50%
6/2/93	0.024	0.029	83%
8/4/93	0.145	0.199	73%
6/28/95	0.018	0.023	78%
8/9/95	0.005	0.015	33%
6/1/99	No Data	0.020	No Data
7/27/99	No Data	0.010	No Data
6/5/01	0.035	0.049	71%
7/16/02	0.023	0.036	64%
		Average	59%

Table 5-50 displays the TSI classification for Gunlock Reservoir using the available TP data. There appears to be a slight worsening trend over the last several years (except for the August 7, 2002 sampling).

Table 5-50. TSI classifications for Gunlock Reservoir based on TP.

Date	TP at station 495051 (mg/L)	TP at station 495052 (mg/L)	TSI Score
5/30/89	No Data	0.01	37
5/31/89	0.01	No Data	37
8/2/89	0.01	0.02	43
5/22/91	0.03	0.03	53
8/7/91	0.01	No Data	37
6/2/93	0.03	0.03	53
8/4/93	0.06	0.02	57
6/28/95	0.02	0.03	51
8/9/95	0.02	0.01	43
6/1/99	0.02	0.01	43
7/27/99	0.01	0.03	47
6/5/01	0.05	0.06	62
8/16/01	0.02	No Data	47
7/16/2002	0.04	0.03	55
8/7/2002	0.01	0.01	37

Table 5-35 displays the TSI classification for Gunlock Reservoir according to secchi disk depth. Conditions have not changed significantly over time.

Table 5-51. TSI classifications for Gunlock Reservoir based on Secchi Depth.

Date	Secchi Depth (m) at station 495051	Secchi Depth (m) at station 495052	TSI Score
5/30/89	No Data	2.5	47
5/31/89	2.5	No Data	47
8/2/89	2.5	1.7	49
5/22/91	4	4	40
8/7/91	2.1	No Data	49
6/2/93	1.4	1.4	55
8/4/93	2.7	2.2	47
6/28/95	2.9	3	44
8/9/95	2.4	2.8	46
6/12/97	2	2.1	50
8/27/97	2	1.8	51
6/1/99	3.6	No Data	42
7/27/99	2.4	1.9	49
6/5/01	No Data	5	37
8/16/01	2.3	2.5	47
7/16/02	1	1	60
8/7/02	1.3	1.5	55

The chlorophyll *a* data for Gunlock Reservoir are shown in Table 5-52. They indicate that the reservoir is classified as oligotrophic based on the data collected during the past four assessments.

Table 5-52. Summary of available chlorophyll *a* data for Gunlock Reservoir.

Date	Chlorophyll *a* at station 495051 (μg/L)	TSI Score
5/31/1989	2.4	39
8/2/1989	5.1	47
5/22/1991	3	41
8/7/1991	2	37
6/2/1993	5.1	47
8/4/1993	3.5	43
6/28/1995	6.4	49
8/9/1995	4.4	45
6/12/1997	5	46
8/27/1997	6.3	49
6/1/1999	1.8	36
7/27/1999	1.3	33
6/5/2001	0.7	27
8/16/2001	0.2	15
07/16/2002	6.4	49
08/07/2002	0.2	15

A summary of the algal taxa collected from Gunlock Reservoir is presented in Table 5-53 to Table 5-56. Phytoplankton was sampled on August 27, 1997, July 27, 1999, July 7, 2002, and October 9, 2002. The algal biomass consisted of diatoms, flagellates, green and yellow green algae, and blue green algae. On August 27, 1997, the major groups contributing to algal biomass (98%) were flagellates including *Pteromonas* (46%) and diatoms (26%) including *Fragilaria crotonensis*, a diatom indicating oligotrophic conditions. There were very few blue green algae present, and included only *Anabaena circinalis*. Blue green algae comprised approximately one percent of the relative density of the algal sample taken from the reservoir.

On July 27, 1999 the major group contributing to algal biomass was overwhelmingly diatoms (93%). The diatom *Fragilaria crotonensis* (81%) indicates oligotrophic conditions. There were no blue green algae present in the algal sample taken in the reservoir at this time. Some green algae were present (4%) in the algal sample, including *Micasterias* that is an indicator of clean water and oligotrophic conditions. There was also a mix of clean and polluted water flagellates (<3%) in the algal sample.

Data collected in August 2002 showed a higher proportion of blue green algae, with *Microcystis Incerta* being dominant. However, no blue green algae were observed during the October 2002 sampling.

Table 5-53. Algal Taxa Present Collected from Gunlock Reservoir, August 27, 1997.

Taxon	Rank	Relative Density %	Mean Number per liter	Cell Volume (mm3/l)
Blue Green Algae:				
Anabaena circinalis	6	1.2	89000	0.46037
Green and Yellow Green Algae				
Ankistrodesmus falcatus	15	0	5600	0.0189
Oocystis	10	0.2	16700	0.0973
Sphaerocystis schroeteri	16	0	5600	0.00437
Schroederia setigera	11	0.1	16700	0.04114
Scendesmus bijuga	12	0.1	11100	0.02724
Crucigenia sp.	9	0.3	38900	0.09786
Quadrigula lacustris	7	0.4	50000	0.1668
Diatoms				
Bacillariophyta sp.1	3	22.8	139000	8.896
Bacillariophyta sp.2	4	1.6	122300	0.6116
Melosira granulata angustissima	5	1.3	100100	0.49873
Fragilaria crotonensis	2	25.7	433700	10.008
Asterionella formosa	13	0.1	11100	0.02502
Flagellates				
Pteromonas	**1**	45.9	1084200	17.86762
Euglena sp.	17	0	5600	0.00222
Dinobryon divergens	8	0.3	50000	0.11009
Chlamydomonas sp	14	0.1	5600	0.02224

Table 5-54. Algal Taxa Present Collected from Gunlock Reservoir, July 27, 1999.

Taxon	Rank	Relative Density %	Mean Number per liter	Cell Volume (mm3/l)
Green and Yellow Green Algae				
Oocystis	4	2.9	27800	0.14892
Sphaerocystis schroeteri	9	0.5	5600	0.02724
Micrasterias	8	0.7	5600	0.03558
Diatoms				
Bacillariophyta sp.1	3	4.9	38,900	0.24722
Bacillariophyta sp.2	2	7.1	44,500	0.3614
Fragilaria crotonensis	1	81	100,100	4,1233
Asterionella formosa	11	0.1	5600	0.00667
Flagellates				
Euglena sp.1	7	0.8	5600	0.04114
Mallomonas	6	0.8	5600	0.0417
Dinobryon divergens	5	1	22200	0.04893
Chrysocapsa planktonica	10	0.2	5600	0.00945

Table 5-55. Algal Taxa Present Collected from Gunlock Reservoir, August 7, 2002.

Taxon	Rank	Relative Density %	Mean Number per liter	Cell Volume (mm3/l)
Blue Green Algae				
Microcystis Incerta	1	31.1	59,500	0.89205
Oscillatoria Species	12	0.6	15,700	0.017215
Green and Yellow Green Algae				
Ankistrodesmus Falcatus	15	0.2	6,300	0.004914
Oocytis Borgei	10	1.3	9400	0.03756
Oocystis Gigas	8	2.6	12,500	0.07512
Oocystis Species	16	0.2	3,100	0.004695
Oocystis Species	9	1.6	31,300	0.04695
Pediastrum Species	6	6.5	3,100	0.1878
Pteromonas Species	13	0.4	25,000	0.011518
Sphaerocystis Schroeteri	2	19.4	12,500	0.556689
Straurastrum Gracile	5	7.1	3,100	0.20345
Unknown Spherical Chlorophyta	7	4.6	131,500	0.13146
Diatoms				
Centric Diatoms	17	0.1	3,100	0.002191
Fragilaria Crotonensis	4	9.0	6,300	0.257912
Melosira Granulata Var Angustissima	11	1.0	6,300	0.028796
Pennate Diatoms	14	0.3	12,500	0.010046
Stephanodiscus Niagarae	3	14.0	12,500	0.40064

Table 5-56. Algal Taxa Present Collected from Gunlock Reservoir, October 9, 2002.

Taxon	Rank	Relative Density %	Mean Number per liter	Cell Volume (mm3/l)
Green and Yellow Green Algae				
Lyngbya Birgei	2	10.3	31,300	1.565
Oocytis Borgei	7	0.2	9,400	0.03756
Pteromonas Species	8	0.0	12,500	0.005759
Sphaerocystis Schroeteri	5	2.8	9,400	0.417517
Diatoms				
Fragilaria Crotonensis	6	0.9	3,100	0.128956
Melosira Granulata	1	76.3	1,180,000	11.564098
Pennate Diatoms	9	0.0	3,100	0.002504
Stephanodiscus Niagarae	4	4.6	21,900	0.70112
Flagellates				
Ceratium Hirundinella	3	4.8	18,800	0.731068

Table 5-57 and Figure 5-40 summarize the TSI scores for Gunlock Reservoir for all dates when TP, secchi disk depth, and chlorophyll *a* data are available. In summary, the TP, transparency, and dissolved oxygen data indicate that Gunlock Reservoir is slightly impaired with conditions declining between 1989 and 1995 and improving from 1999 to 2001. Based on these results it is recommended that TP loads to Gunlock Reservoir be reduced to continue the improving trend. The transparency and dissolved oxygen impairments are related to the excessive TP loading and will improve due to the link between TP, algae, and dissolved oxygen described above for the Baker Dam Reservoir TMDL. The results of the TP TMDL are presented below.

Table 5-57. Summary of TSI scores for Gunlock Reservoir for all dates for which phosphorus, secchi, and chlorophyll a data are available.

Date	TSI Score for Phosphorus	TSI Score for Secchi Depth	TSI Score for Chlorophyll a	Average TSI Score	TSI Classification
5/31/1989	37	47	39	41	Mesotrophic
8/2/1989	43	49	47	46	Eutrophic
5/22/1991	53	40	41	45	Eutrophic
8/7/1991	37	49	37	41	Mesotrophic
6/2/1993	53	55	47	52	Eutrophic
8/4/1993	57	47	43	49	Eutrophic
6/28/1995	51	44	49	48	Eutrophic
8/9/1995	43	46	45	45	Eutrophic
6/1/1999	43	42	36	40	Oligotrophic
7/27/1999	47	49	33	43	Mesotrophic
6/5/2001	62	37	27	42	Mesotrophic
8/16/2001	47	47	15	36	Oligotrophic
7/16/2002	45	60	49	51	Eutrophic
8/7/2002	37	55	15	36	Oligotrophic

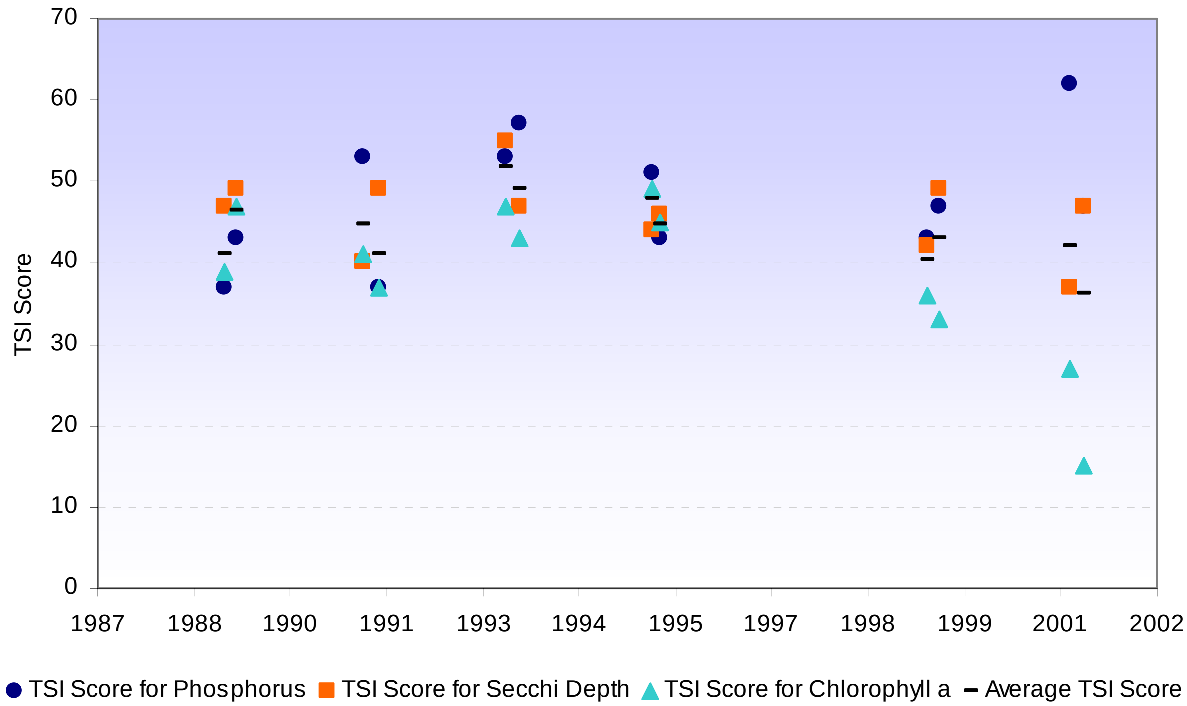


Figure 5-40. Summary of TSI scores for Gunlock Reservoir for all dates for which phosphorus, secchi, and chlorophyll a data are available.

5.7.1 Modeling

The BATHTUB model was used to estimate the load reductions necessary to meet the TP recommended value of 0.025 mg/L. The model was first calibrated and validated to existing conditions and then used to evaluate various load reduction scenarios. Approximately a 30 percent reduction in loads was determined to be necessary to meet the 0.025 mg/L target.

Table 5-58 provides the estimated TP loads from each of the significant sources above Gunlock Reservoir. The primary sources of TP to Gunlock Reservoir are livestock and failing septic systems. The following assumptions were used to estimate the loading of TP to the reservoir:

- Approximately 750 cattle are located in the watershed above Gunlock Reservoir, which includes the 500 cattle estimated to be upstream of Baker Dam Reservoir. This estimate is based on observations made during the field assessments. It should also be noted that cattle were observed grazing right along the high water mark of Gunlock Reservoir during the field assessment. A typical TP generation rate of 0.017 kg/day/animal was assumed based on literature values for the TP concentration of manure (0.05 kg/ P_2O_5/455 kg/animal/day) and a representative animal weight of 350 kg (NRCS, 1999).
- Approximately 50 septic systems are located above Gunlock Reservoir in the town of Central (Hansen, Allen, and Luce, 1997) and 40 are located in the town of Gunlock. Twenty-five percent of these systems are assumed to deliver phosphorus to the Santa Clara either due to failing systems or their close proximity to the river.
- There are only about 850 acres of irrigated land above the reservoir, primarily using sprinkler irrigation.

- Internal loading contributes to TP due to the occasional days when the lower depths of the reservoir are anoxic. Under certain conditions, bottom sediments can be important sources of phosphorus to the overlying waters of reservoirs, particularly if the reservoir is shallow or has an anaerobic hypolimnium (Chapra, 1997). Phosphorus flux from sediment deposits is strongly affected by sediment composition and oxygen levels in the water column; sediment release can contribute significant nutrient loadings during low-oxygen conditions. The estimated internal loading for Gunlock Reservoir is 510 kg/yr based on the results of the BATHTUB modeling. The phosphorus sedimentation term in BATHTUB is net sedimentation–that is, it represents the rate of phosphorus settling minus the rate of resuspension/regeneration from the sediment. The difference between an estimate of phosphorus deposition based on a phosphorus budget model (Chapra, 1997) and the BATHTUB net sedimentation rate was interpreted as internal loading.

Table 5-58. Sources of TP to Gunlock Reservoir.

Source Category	Load (kg/yr)	Percent
Land Erosion/Streambank Erosion	1,110	43%
Livestock	920	36%
Internal Loading	510	20%
Septic Systems	30	1%
Total	2,570	100%

The TP TMDL for Gunlock Reservoir is summarized in Table 5-59. The WLA is zero because there are no point sources. The critical condition for the load reductions is during the summer months when climatic conditions are most conducive to algal growth. The next section of the document discusses activities that should be implemented to achieve the necessary load reductions are discussed below.

Table 5-59. Summary of the TP TMDL for Gunlock Reservoir.

Expressed as Endpoints

- Reduction of in-reservoir TP concentration to 0.025
- DO concentrations above 4.0 mg/L in greater than 50 percent of water column
- TSI values between 40 and 50
- Continued dominance of non-blue-green algae
- No fish kills

Expressed as Loads

Existing Load (kg/yr)	Loading Capacity (kg/yr)	WLA (kg/yr)	LA (kg/yr)	MOS (kg/yr)	Reduction (kg/yr)	Reduction (Percent)
2570	1830	0	1738	92	832	32%

Sediment eroded out of the Santa Clara River is deposited into Gunlock Reservoir, as evidenced by the delta deposit of fine sediments.

6.0 IMPLEMENTATION

6.1 Background

The purpose of this section of the document is to describe the activities necessary to achieve the load reductions described above. Implementation has been a central aspect of the TMDL development process in the Virgin River and the identification of possible implementation activities was a focus of both the field and aerial surveys. The implementation activities described below are also being incorporated into the broader Virgin River Watershed Management Plan and more specific roles and responsibilities for implementation will be identified by the Virgin River Management Plan Coordinating Committee and the Watershed Advisory Committees.

Many of the impairments in the Virgin River watershed occur during low flow summer conditions when pollutants tend to be concentrated and transport and resident times are decreased. However, in the case of TDS, saline soils are eroded out and transported to the waterbodies during storm driven flood events. The implementation strategies discussed here are therefore designed to both reduce the loadings introduced during the storm events, and to minimize their impacts during the critical summer low flow season.

Figure 6-1 displays the necessary load reductions geographically. Because many of the proposed best management practices will result in reduced loads of multiple parameters, one single TMDL implementation plan can be developed that takes into account all of the sources

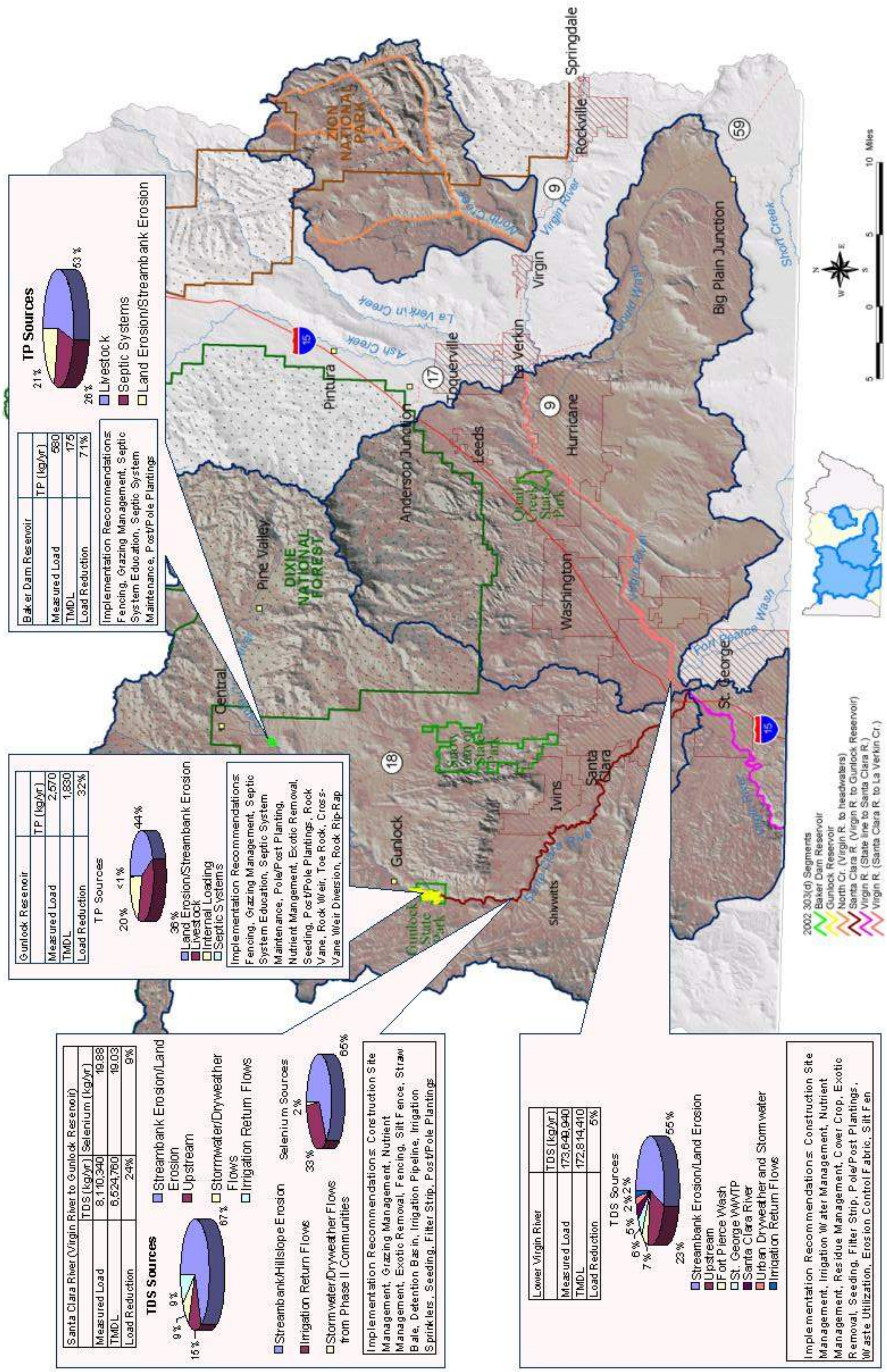


Figure 6-1. Load reductions in the Virgin River watershed.

To provide more specific implementation recommendations the Virgin River watershed has been categorized into smaller segments. Figure 6-2 shows the segmentation of the watershed into smaller segments and a suite of BMPs have been identified for each segment. The combined impact of these implementation activities is expected to result in the necessary load reduction and to also decrease the impact of these source loadings during the critical summer condition. Implementation of these BMPs and load reduction strategies should therefore result in achieving water quality standards.

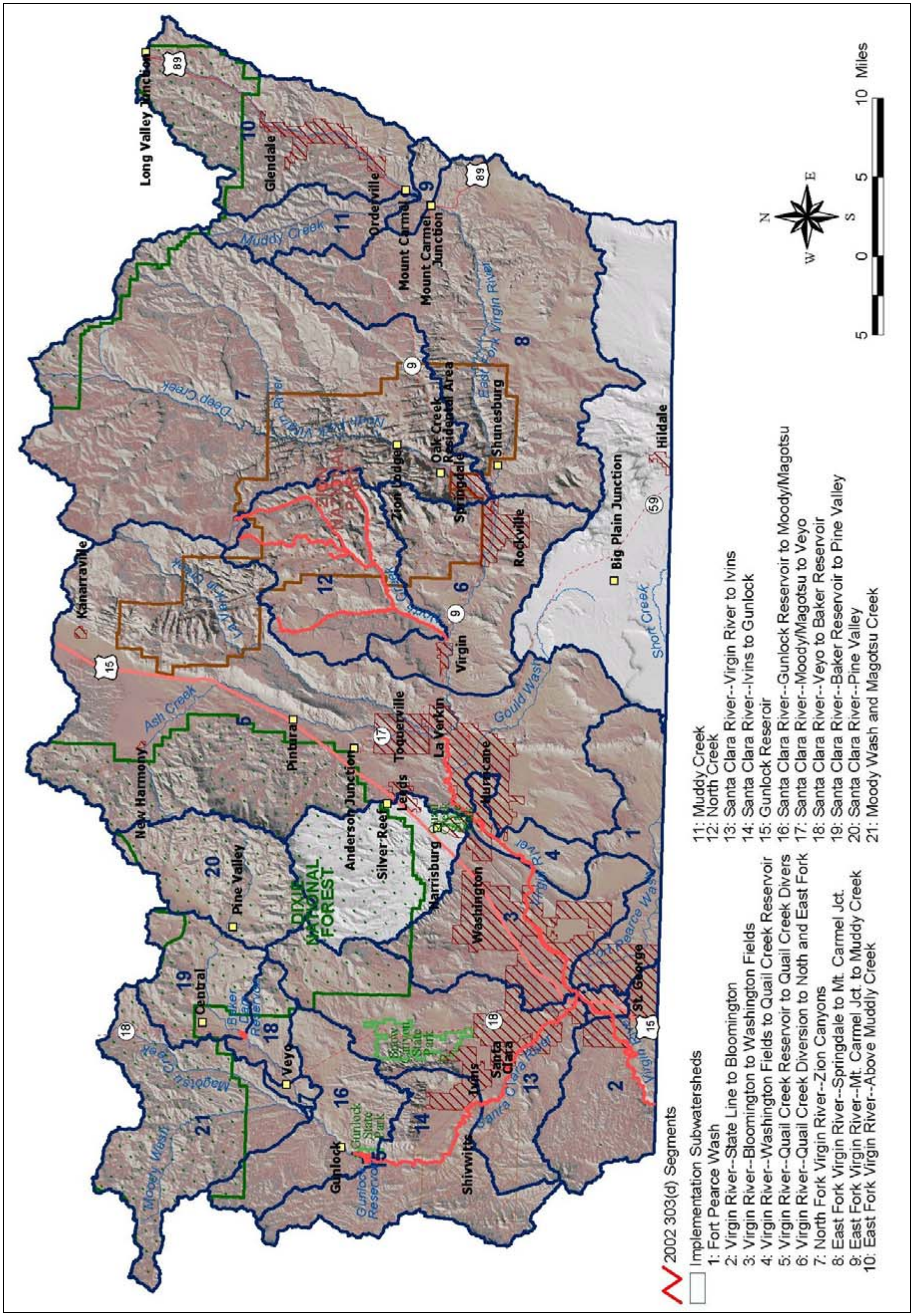


Figure 6-2. Virgin River watershed implementation subwatersheds.

6.2 Schedule

It is important to realize that TMDL implementation activities can take multiple years to achieve meaningful and lasting pollutant reductions and improved water quality conditions. The existing impairments are a result of decades of activities that cannot be reversed overnight. The implementation strategies and recommendations discussed here are focused to achieve improvements in overall water quality throughout the entire watershed. Although some activities might result in relatively rapid water quality improvements, most activities will require a long time to take effect.

The implementation of these TMDLs should rely on a long-term approach. Watershed projects should be started incrementally as they are planned and funded. The time frame for implementation is estimated to be 15 years (Table 6-1). The time frame estimated for improving the water quality is 5 to 15 years, depending upon several variables. Factors that could affect the speed of the reduction strategies include both human factors and natural conditions. Much of the schedule is dependent upon the efforts and time invested in securing partners to implement BMPs and fund demonstration projects that can be used as examples to involve and educate the public and stakeholders.

Table 6-1. Schedule of Virgin River TMDL implementation activities.

Implementation Actions	Implementation Year Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Public Outreach & Involvement	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Establish Milestones	X					X					X				
Public Education & Involvement	X	X	X	X	X										
Demonstration Projects	X	X	X	X	X										
Secure Project Funding	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Implement BMPs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Determine BMPs Effectiveness				X					X						X
Re-evaluate Milestones and Strategies					X					X					

Once BMPs are installed, the natural conditions and variability of the ecosystem will also play a part in the time frame for achieving water quality standards, as it takes varying flows and time to erode out and stabilize channels, and to flush pollutants from a system. USEPA has recognized that TMDLs with primarily nonpoint sources of pollution can be very difficult to manage and that it might take a long time to correct the problems.

The sections below identify specific types of BMPs that are especially appropriate for various segments of the Virgin River watershed. Additional information on each type of BMP is provided in Appendix B.

6.3 Santa Clara River Watershed

The Santa Clara River was listed as impaired due to temperature and TDS from its confluence with the Virgin River to Gunlock Reservoir. The Santa Clara River is expected to be listed as impaired due to temperature in the 2004 303)d) list. Selenium is also considered a potential cause of impairment in this segment. Based on the currently available data and the current riparian vegetation and geomorphic conditions, it does not appear that a temperature TMDL for the Santa Clara River is warranted.

Therefore, the implementation plan does not focus specifically on reducing in-stream temperatures. However, some of the recommended BMPs will result in improved riparian vegetation, which in turn will help provide additional shading.

The selenium TMDL indicates that a 9 percent reduction in the current measured load is required to achieve the TMDL load allocation. The critical condition for the load reductions is the months of March and April when existing concentrations are at their greatest. The TMDL load allocation recommends a 24 percent reduction in annual TDS loads to achieve water quality standards. Critical condition are the spring and summer (April to October), because these are the months when TDS concentrations are at the highest and irrigation activities are at their peak. The sources of TDS include storm and dry weather urban flows, streambank and hillslope erosion, and irrigation return flows.

Within the following stream segments and corresponding sub-watersheds, the following BMP activities are recommended as part of the overall implementation strategy for the Santa Clara River watershed. It should also be noted that Thompson and Hardy (2003) includes a wealth of data on habitat conditions in the Santa Clara River. These data can be reviewed to obtain the most beneficial areas for BMPs. For example, Thompson and Hardy indicate that the following reaches had poor bank stability:

- Cluster 2: between the confluence with the Virgin River and St. George Fields Diversion.
- Cluster 10: primarily between Winsor Dam and the beginning of reach SC07 (about 1 km upstream of the Shivwits Reservation northern boundary).
- Cluster 14: between the Gunlock Diversion and Smith Diversion near the downstream end of Veyo Canyon.

6.3.1 Santa Clara River: Virgin River Confluence - Ivins:

This stream segment is considerably more populated than the upper reaches of the Santa Clara River because it is located near St. George. This area is currently experiencing rapid growth and development as the population continues to increase. Historic agricultural fields along the stream are giving way to new subdivisions and golf courses.

Table 6-2 identifies BMPs that could be implemented to reduce the existing loads of TDS within this stream segment and subwatershed (see Appendix B for more details).

Table 6-2. BMPs recommended to reduce the loadings and impacts in the Santa Clara River from the Virgin River confluence to Ivins.

Practice Number	Practice Name	Intensity Level
100	Construction Site Management	Passive Management
120	Grazing Management	Passive Management
160	Nutrient Management	Passive Management
210	Exotic Removal	Active Management
220	Fencing	Active Management
221	Seeding	Active Management
240	Filter Strip	Active Management
260	Pole/Post Plantings	Active Management
333	Silt Fence	Mild Engineering
400	Detention Basin	Moderate Engineering
450	Irrigation Pipeline	Moderate Engineering

Table 6-3 and Table 6-4 provide an estimate of the impact of two potential sets of BMPs for the Santa Clara River below Gunlock Reservoir to demonstrate that the necessary TDS and selenium load reductions are achievable. A variety of other combinations of BMPs are also available to achieve the necessary load reductions and the final selection should be based on local input and recommendations. Specific reach locations that would benefit from BMPs are also identified by Thompson and Hardy (2003).

Table 6-3. Estimated impact of one potential set of best management practices for the Santa Clara River below Gunlock Reservoir to meet the TDS TMDL.

Practice Number	Practice Name	Extent of Practice	Estimated Impact to Source Categories	Resulting Load Reduction (kg/yr)
NA	Water Conservation	Continued water conservation efforts to reduce urban runoff and dry weather flows	25 percent reduction from urban dry weather and storm flows	174,340
220	Fencing	Establish fencing to exclude livestock in heavily trampled areas	5 percent reduction from streambank erosion	276,560
260	Pole/Post Plantings	Install pole/post plantings to improve streambank stability and vegetation conditions	10 percent reduction from streambank erosion	553,120
400	Detention Basin	Install detention basins in targeted locations to capture urban dry weather and storm flows	25 percent reduction from urban dry weather and storm flows	174,340
210	Exotic Removal	Remove 50 percent of salt cedar to improve instream flows and reduce TDS loadings	Improve flow conditions, resulting in decreased TDS concentrations equivalent to a 5 percent reduction in overall load	405,517
450	Irrigation Pipeline	Install additional irrigation pipeline to increase efficiencies	Improving efficiencies by 5 percent will reduce load from irrigation return flows by 15 percent	104,460
221	Seeding	Seed 500 acres of poorly covered ground to reduce sheet and rill erosion	5 percent reduction from land erosion	276,560
		Total Estimated Load Reduction		**1,964,897**
		Total Necessary Load Reduction (from TMDL Analysis)		**1,911,820**

Table 6-4. Estimated impact of one potential set of best management practices for the Santa Clara River below Gunlock Reservoir to meet the selenium TMDL.

Practice Number	Practice Name	Extent of Practice	Estimated Impact to Source Categories	Resulting Load Reduction (kg/yr)
220	Fencing	Establish fencing to exclude livestock in heavily trampled areas	5 percent reduction from streambank erosion	0.65
210	Exotic Removal	Remove 50 percent of salt cedar to improve instream flows and reduce loadings	Improve flow conditions, resulting in decreased selenium concentrations equivalent to a 5 percent reduction in overall load	1.0
450	Irrigation Pipeline	Install additional irrigation pipeline to increase efficiencies	Improving efficiencies by 5 percent will reduce load from irrigation return flows by 15 percent	1.0
			Total Estimated Load Reduction	**2.65**
			Total Necessary Load Reduction (from TMDL Analysis)	**1.80**

6.3.2 Santa Clara River: Ivins - Gunlock Reservoir:

Flow in this portion of the Santa Clara River is intermittent and dependent upon releases from Gunlock Reservoir. The majority of land uses in this portion of the watershed are a mixture of limited agriculture, livestock grazing, and dispersed recreation. Much of the stream corridor runs through the Shivwits Paiute Reservation. Riparian vegetation is composed predominantly of native species with some exotic species sparsely mixed in. Within this portion of the watershed there are extensive areas of erosive shale formations, which are especially evident on the south side of the Santa Clara River. Significant improvements to water quality in this segment of the Santa Clara are expected as a result of the Pipeline Project, which is intended to allow more water to remain in-stream to increase the base flows during the winter when the stream is now often dry. The water quality of the pipeline water may also serve as a dilution factor, due to the potential higher water quality conditions of the piped water.

Sources of pollutant loadings:

- Natural hill-slope erosion
- Livestock grazing
- Dispersed recreational uses

Table 6-5 identifies a variety of BMPs that would be appropriate for reducing existing TDS in this stream segment and subwatershed (see Appendix B for more details).

Table 6-5. BMPs recommended to reduce the loadings and impacts in the Santa Clara River from Ivins to Gunlock Dam.

Practice Number	Practice Name	Intensity Level
120	Grazing Management	Passive Management
160	Nutrient Management	Passive Management
220	Fencing	Active Management
333	Silt Fence	Mild Engineering

6.3.3 Gunlock Reservoir

Gunlock Reservoir is located near the town of Gunlock on the Santa Clara River and is listed for dissolved oxygen and total phosphorus impairments. The BATHTUB model was used to estimate the load reductions necessary to meet the TP recommended value of 0.025 mg/L, and it was determined that a 32 percent reduction in loads is required to meet the 0.025 mg/L target. The primary sources of TP are believed to be livestock, stream-bank erosion, and failing septic systems.

Gunlock Reservoir is the largest water storage impoundment on the Santa Clara River. Water is captured in Gunlock Reservoir and stored for downstream domestic and agricultural uses throughout the year. The reservoir is also used for recreation (boating, fishing, etc.) and by livestock grazing along the shores.

Sources of pollutant loadings directly around the Gunlock Reservoir shoreline are livestock grazing. Potential implementation practices to address this source are shown in Table 6-6.

Table 6-6. Recommended implementation practices for Gunlock Reservoir.

Practice Number	Practice Name	Intensity Level
120	Grazing Management	Passive Management
220	Fencing	Active Management

6.3.4 Moody and Magotsu Canyons

Nearby lands alongside these stream channels are sparsely settled. The adjacent lands are utilized for traditional small-scale agricultural and livestock grazing, often in the channel itself. Magotsu Creek is primarily an intermittent stream, while Moody Wash's base flow appears limited to the reach near the confluence of the two streams. Riparian vegetation is a mixture of native and exotic species. The surrounding landscape is composed of extensive exposures of erodible shale formations that likely contribute to background TDS levels due to surface erosion and dissolution.

Sources of pollutant loadings:

- Natural hill-slope erosion
- Livestock grazing
- Stream-bank erosion

Table 6-7 identifies BMPs that could be implemented to reduce the existing load of TP in this stream segment and subwatershed (see Appendix B for more details).

Table 6-7. BMPs recommended to reduce the loadings and impacts in Moody and Magotsu Canyons.

Practice Number	Practice Name	Intensity Level
120	Grazing Management	Passive Management
220	Fencing	Active Management

6.3.5 Santa Clara River: Gunlock Reservoir - Moody and Magotsu Canyons:

Within this reach the Santa Clara River valley widens significantly. Several agricultural fields lie along the Santa Clara River. The existing irrigation systems in use in this portion of the watershed are predominately sprinkler systems, thus limiting the quantity of the water diverted for irrigation and decreasing the irrigation return flows. In some areas the stream banks are stable and well vegetated, however in other stream segments, stream bank erosion is a common occurrence. The riparian vegetation is predominantly comprised of the native coyote willow, desert willow, and cottonwood.

Sources of pollutant loadings:

- Natural hill-slope erosion
- Limited agricultural runoff
- Domestic septic systems
- Minor stormwater run-off impacts
- Livestock in the stream
- Stream-bank erosion
- Extensive sand and gravel mining causing major impacts

Table 6-8 identifies BMPs that could be implemented to reduce the existing loads of TP in this stream segment and subwatershed (see Appendix B for more details).

Table 6-8. BMPs recommended to reduce loadings and impacts in the Santa Clara River from Gunlock Dam Reservoir to Moody and Magotsu Canyons.

Practice Number	Practice Name	Intensity Level
120	Grazing Management	Passive Management
160	Nutrient Management	Passive Management
190	Residue Management	Passive Management
210	Exotic Removal	Active Management
220	Fencing	Active Management
221	Seeding	Active Management
260	Pole/Post Plantings	Active Management
421	Rock Vane	Moderate Engineering
422	Rock Weir	Moderate Engineering
423	Toe Rock	Moderate Engineering
520	Cross-Vane Weir Diversion	Intense Engineering
521	Rock Rip-Rap	Intense Engineering
522	Stream Channel Stabilization	Intense Engineering

6.3.6 Santa Clara River: Moody and Magotsu Canyons - Veyo

The Santa Clara River flows through a narrow and largely inaccessible basalt canyon in this reach. Very little, if any, human activity takes place in this segment of the Santa Clara River watershed. Riparian vegetation is dominated by native species. This segment lacks any apparent anthropogenic sources, therefore there are no BMPs recommended for this stream segment and subwatershed.

Sources of pollutant loadings:

- Natural hill-slope erosion

Table 6-9 provides an estimate of the impact of one potential set of BMPs for segments above Gunlock Reservoir to demonstrate that the necessary TP load reductions are achievable. A variety of other combinations of BMPs are also available to achieve the necessary load reductions and the final selection should be based on local input and recommendations.

Table 6-9. Estimated impact of one potential set of BMPs to meet the Gunlock Reservoir TP TMDL.

Practice Number	Practice Name	Extent of Practice	Estimated Impact to Source Categories	Resulting Load Reduction (kg/yr)
220	Fencing	Exclude livestock from grazing adjacent to reservoir or Santa Clara River	Reduction of 25 percent of current livestock loads	208
120	Off-site Watering	Exclude livestock from grazing adjacent to reservoir or Santa Clara River	Reduction of 25 percent of current livestock loads	208
120	Control surface flows	Control spring runoff to reduce loading to reservoir	Reduction of 25 percent of current livestock loads	208
522	Stream Channel Stabilization	Restore natural pattern and profile of Santa Clara affected by sand and gravel operation	Reduction of 20 percent of streambank erosion	226
		Total Estimated Load Reduction		**850**
		Total Necessary Load Reduction (from TMDL Analysis)		**832**

6.3.7 Santa Clara River: Veyo – Baker Dam Reservoir

Baker Dam Reservoir is located in the uppermost section of the Santa Clara River watershed and is listed as impaired for dissolved oxygen and total phosphorus. The BATHTUB model was used to estimate the load reductions necessary to meet the TP pollution indicator value of 0.025 mg/L. The results of the modeling and the TMDL indicate that approximately a 70 percent reduction in the current measured loads is necessary to meet the 0.025 mg/L target. The primary sources of the excessive TP loads are believed to be livestock and failing septic systems. A separate analysis indicates that temperatures in the Santa Clara River must be reduced from a current average of 21.5 ºC in July and August to 20 ºC to meet the temperature standard.

Baker Reservoir is a relatively small impoundment located on the Santa Clara River and it stores and releases water for downstream irrigation demands. The community of Brookside is located along the stream channel below the reservoir. Housing in Brookside is relatively dense, directly adjacent to the Santa Clara River along both banks. The cumulative impact of the individual septic waste systems on water quality is undocumented, however it is highly likely that these septic system contribute nutrients that lead to both increased TDS in-stream, and higher nutrient loadings that accumulate downstream in Gunlock Reservoir. The dam itself limits the duration and size of the flood flows, and the riparian vegetation is lush and dominated by native species throughout most of this reach. Stream banks are mostly stable. A natural hot spring, which has been developed for recreational uses, is located near the town of Veyo. This hot spring likely contributes increased TDS loads to the Santa Clara River that are naturally high due to the geology and geothermic activity. The town of Veyo is predominantly septic systems, and could be a minor source of TDS loadings and nutrients.

Sources of pollutant loadings:

- Natural hill-slope erosion
- Domestic septic systems
- Limited stormwater runoff from driveways and roads
- Natural hot springs

6.3.8 Santa Clara River: Baker Reservoir - Pine Valley

The Santa Clara River runs through a steep and largely inaccessible gorge within this reach. The riparian vegetation is robust and largely native. Irrigation diversions reduce the base flows during the growing season. The narrow canyons limit livestock and agriculture uses. Because of the very few sources present in this inaccessible reach of stream, there are not any BMPs that are recommended for load reductions in this segment for the Santa Clara River.

Sources of pollutant loadings:
- Natural hill-slope erosion
- Dispersed recreation
- Very few livestock present

6.3.9 Santa Clara River: Pine Valley Area and the Headwaters

The Santa Clara River originates in the Pine Valley Mountains and is managed by the USDA Dixie National Forest. There are no obvious loads associated with the forest service lands. A small reservoir is located adjacent to a campground near the forest boundary. Pine Valley is a bowl shaped valley dominated by a large wet meadow primarily utilized for livestock grazing. Historically, the valley was sparsely populated but the cool climate is spurring an increasing number of seasonal and permanent homes in the valley. These new homes are all on septic systems, with some set in the wet meadow soils, but a majority on upper hillslopes. These septic systems can contribute nutrients that eventually end up in Baker Dam Reservoir. The stream channel incised some time in the past and is now widening. Stream bank erosion is widespread throughout the Pine Valley area. The native willow community is dominated by older, mature individuals, and seems to be lacking good recruitment of saplings and juvenile plants. Current grazing management practices may be responsible for reducing the successful recruitment of new willow age classes. If the current increasing population trend continues it may be necessary to install a waste water treatment facility in the Pine Valley area.

Sources of pollutant loadings:
- Natural hill-slope erosion
- Livestock grazing
- Stream bank erosion
- Domestic septic systems

The implementation practices shown in Table 6-10 should be used to obtain the necessary reductions in TP loads to affect load reductions in Baker Dam Reservoir downstream.

Table 6-10. Recommended implementation practices for upstream of Baker Dam Reservoir in the Pine Valley area and Santa Clara River headwaters.

Practice Number	Practice Name	Intensity Level
160	Nutrient Management	Passive Management
333	Silt Fence	Mild Engineering
400	Detention Basin	Moderate Engineering
460	Septic System Maintenance	Moderate Engineering
470	Road Stabilization	Moderate Engineering
120	Fencing	Passive Management
120	Off-site watering	Passive Management

Table 6-11 provides an estimate of the impact of one potential set of BMPs for segments above Baker Dam Reservoir to demonstrate that the necessary TP load reductions are achievable. A variety of other combinations of BMPs are also available to achieve the necessary load reductions and the final selection should be based on local input and recommendations. Thompson and Hardy (2003) identify specific reach locations that would benefit from BMPs.

Table 6-11. Estimated impact of one potential set of BMPs to meet the Baker Dam Reservoir TP and temperature TMDLs.

Practice Number	Practice Name	Extent of Practice	Estimated Impact to Source Categories	Resulting TP Load Reduction (kg/yr)
220	Fencing	Exclude livestock from grazing adjacent to reservoir or Santa Clara River	Reduction of 25 percent of current livestock loads	80
120	Grazing Management	Off-site watering, prescribed grazing	Reduction of 50 percent of current livestock loads	155
460	Septic System Maintenance	Fix or replace failing septic systems	Reduce septic system loads by 75 percent	113
260	Pole/Post Plantings	Re-establish native vegetation along most severely eroding streambanks	Reduce streambank erosion by 55 percent Reduce tributary temperatures by 1.5 ºC	67
		Total Estimated Load Reduction		**415**
		Total Necessary Load Reduction (from TMDL Analysis)		**414**

6.4 Virgin River Watershed

Two segments of the Virgin River and the North Creek are impaired due to TDS. After reviewing the data no TMDL is being recommended for North Creek. The two segments of the Virgin River that appear on the 2002 303(d) list as impaired due to excessive TDS are the Virgin River from the Arizona/Utah border to the Santa Clara River, and the Virgin River from the Santa Clara confluence to Quail Lake Diversion. Based on an evaluation of the existing data, a site-specific criterion for the Virgin River has been proposed because natural concentrations of TDS are above the statewide standard. However, there are several anthropogenic impacts in the lower Virgin River watershed that are significantly increasing the concentration of these natural sources, and are further contributing additional loadings to the river. Therefore, it is necessary to identify all possible load reduction scenarios and BMPs that can be utilized to improve the water quality of the lower Virgin River.

6.4.1 Virgin River: Arizona Border - Bloomington

This reach is largely undeveloped with very little observable impacts, and no sources of significant pollutant loadings. The channel is confined by a shallow bedrock gorge. The riparian vegetation is dominated by salt cedar and there is only limited evidence of stream bank erosion or livestock impacts in this river segment.

Sources of pollutant loadings:

- Natural sources
- Exotic vegetation

Table 6-12 identifies BMPs that could be implemented to reduce existing loads of TDS within this stream segment and subwatershed (see Appendix B for more details).

Table 6-12. BMPs recommended to reduce the loadings and impacts in the Virgin River from the Arizona-Utah border to Bloomington.

Practice Number	Practice Name	Intensity Level
210	Exotic Removal	Active Management
221	Seeding	Active Management
260	Pole/Post Plantings	Active Management

6.4.2 Fort Pierce Wash

Fort Pierce Wash is an ephemeral tributary entering the Virgin River from the south. The channel has been significantly altered due to the extensive sand and gravel mining operations in the active stream channel. There appears to be perennial flows entering the Fort Pierce Wash as a result of ground water return flows caused by the irrigation activities in the Washington Fields. Along this stream segment there are numerous new developments, and many construction sites that generate run-off laden with sediments. There appeared to be a lack of adequate stormwater run-off controls at the construction sites and new developments were lacking stormwater detention basins. Domestic and golf course irrigation and fertilization of lawns and golf courses, create year-round runoff laden with nutrients that can lead to increased TDS levels being delivered to the Virgin River through the Ft. Pierce Wash drainage.

Sources of pollutant loadings:

- Saline irrigation return flows
- Nutrient runoff
- Urban stormwater run-off
- Major disturbance from sand and gravel mining
- Stream-bank erosion
- Stream channel alterations
- Construction disturbances
- Lack of stormwater detention basins

Table 6-13 identifies BMPs that could be implemented to reduce these existing loads of TDS within this stream segment and subwatershed. (see Appendix B for more details):

Table 6-13. BMPs recommended to reduce the loadings and impacts in Ft. Pierce Wash.

Practice Number	Practice Name	Intensity Level
100	Construction Site Management	Passive Management
140	Irrigation Water Management	Passive Management
160	Nutrient Management	Passive Management
190	Residue Management	Passive Management
200	Cover Crop	Active Management
210	Exotic Removal	Active Management
221	Seeding	Active Management
240	Filter Strip	Active Management
260	Pole/Post Plantings	Active Management
270	Waste Utilization	Active Management
331	Erosion Control Fabric	Mild Engineering
333	Silt Fence	Mild Engineering
334	Straw Bale	Mild Engineering
400	Detention Basin	Moderate Engineering
421	Rock Vane	Moderate Engineering
422	Rock Weir	Moderate Engineering
423	Toe Rock	Moderate Engineering
450	Irrigation Pipeline	Moderate Engineering
452	Irrigation Sprinklers	Moderate Engineering
454	Irrigation Tail water Recovery	Moderate Engineering
520	Cross-Vane Weir Diversion	Intense Engineering
521	Rock Rip-Rap	Intense Engineering
522	Stream Channel Stabilization	Intense Engineering

6.4.3 Virgin River: Bloomington - Washington Fields Diversion:

The communities of St. George, Washington, and Bloomington completely surround this segment of the Virgin River. The large agricultural area of Washington Fields lies along the eastern banks. Nearly all stream base flow is diverted during the growing season at the Washington Fields diversion at the head of the reach. The river channel is restricted in width by the lack of flow, and the extensive growths of exotic salt cedar in the riparian corridor. Stream-bank erosion is widespread although very little development takes place within the 100-year floodplain due to strong local zoning codes. This segment is severely impacted due to anthropogenic uses, management, and developments. Implementation should be focused on limiting the stormwater and irrigation return flows, decreasing the effects of construction and development, and increasing the in-stream base flows during the critical summer months.

Sources of pollutant loadings:

- Natural sources
- Exotic vegetation
- Saline irrigation return flows from tiled fields
- Urban stormwater run-off
- AFOs
- Construction disturbances
- Nutrient runoff
- Inefficient domestic irrigation
- Lack of reclaimed water for golf courses
- Lawn and golf course fertilizer and herbicide runoff during irrigation and precipitation events

- Lack of adequate stormwater detention basins

Table 6-14 identifies BMPs that could be implemented to reduce these existing TDS loads in this stream segment and subwatershed (see Appendix B for more details).

Table 6-14. BMPs recommended to reduce the loadings and impacts in the Virgin River from Bloomington to the Washington Fields Diversion.

Practice Number	Practice Name	Intensity Level
100	Construction Site Management	Passive Management
140	Irrigation Water Management	Passive Management
160	Nutrient Management	Passive Management
190	Residue Management	Passive Management
200	Cover Crop	Active Management
210	Exotic Removal	Active Management
221	Seeding	Active Management
240	Filter Strip	Active Management
260	Pole/Post Plantings	Active Management
270	Waste Utilization	Active Management
331	Erosion Control Fabric	Mild Engineering
333	Silt Fence	Mild Engineering
334	Straw Bale	Mild Engineering
400	Detention Basin	Moderate Engineering
421	Rock Vane	Moderate Engineering
422	Rock Weir	Moderate Engineering
423	Toe Rock	Moderate Engineering
450	Irrigation Pipeline	Moderate Engineering
452	Irrigation Sprinklers	Moderate Engineering
454	Irrigation Tail water Recovery	Moderate Engineering
520	Cross-Vane Weir Diversion	Intense Engineering
521	Rock Rip-Rap	Intense Engineering
522	Stream Channel Stabilization	Intense Engineering

6.4.4 Virgin River: Washington Fields Diversion - Quail Creek Reservoir:

This reach contains Quail Creek Reservoir. Base flows in this segment are greater than those flows found below the diversion. Flows are augmented by the small releases from Quail Creek Reservoir designed to benefit the listed native species, as is instructed in an agreement with the US Fish and Wildlife Service. The channel is constrained laterally by dense thickets of salt cedar, but there are some active floodplains in the lower part of the segment.

Sources of pollutant loadings:

- Exotic vegetation
- Altered habitat
- Off-channel ponds
- Natural hill-slope erosion

Table 6-15 identifies BMPs that could be implemented to reduce existing TDS loads in this stream segment and subwatershed (see Appendix B for more details).

Table 6-15. BMPs recommended to reduce the loadings and impacts in the Virgin River from the Washington Fields Diversion to the Quail Creek Reservoir.

Practice Number	Practice Name	Intensity Level
100	Construction Site Management	Passive Management
210	Exotic Removal	Active Management
221	Seeding	Active Management
260	Pole/Post Plantings	Active Management
333	Silt Fence	Mild Engineering
334	Straw Bale	Mild Engineering
400	Detention Basin	Moderate Engineering

Table 6-16 provides an estimate of the impact of one potential set of BMPs for Virgin River below the Washington Fields diversion to demonstrate that the necessary TDS and selenium load reductions are achievable. The BMPs are focused on sources associated with low flow conditions because these are the periods during which impairments occur. A variety of other combinations of BMPs are also available to achieve the necessary load reductions and the final selection should be based on local input and recommendations.

Table 6-16. Estimated impact of one potential set of BMPs for the Virgin River, from the Washington Fields diversion to UT-AZ State Line, in order to meet the TDS TMDL.

Practice Number	Practice Name	Extent of Practice	Estimated Impact to Source Categories	Resulting Load Reduction (kg/yr)
Load reduction resulting from Santa Clara River TMDL				1,911,820
NA	Water Conservation	Continued water conservation efforts to reduce urban runoff and dry weather flows	25 percent reduction from urban dry weather and storm flows	1,003,628
260	Pole/Post Plantings	Targeted restoration of poor streambank conditions	1 percent reduction in streambank erosion	944,678
210	Exotic Removal	Remove salt cedar to improve instream flows and reduce loadings	Improve flow conditions, resulting in decreased TDS concentrations equivalent to a 2 percent reduction in overall load	3,473,000
400	Detention Basin	Install detention basins in targeted locations to capture urban dry weather and storm flows	25 percent reduction from urban dry weather and storm flows	1,003,628
450	Irrigation Pipeline	Install additional irrigation pipeline to increase efficiencies by reducing the number of open conveyances (ditches, canals, etc.)	Improving efficiencies by 5 percent will reduce load from irrigation return flows by 15 percent	522,317
		Total Estimated Load Reduction		**8,859,071**
		Total Necessary Load Reduction (from TMDL Analysis)		**8,640,720**

6.4.5 North Creek

North Creek enters the Virgin River above the town of Virgin. The headwaters of North Creek lie in the high terrain of Zion National Park. The valley is a narrow bedrock valley and sparsely settled by isolated ranches. Diversions and off-channel ponds are common but the stream is not impounded. Riparian vegetation is robust and largely native. Surrounding hill-slopes are dominated by extensive exposures of highly erosive shale formations that contribute to background TDS loads. While no TMDL was deemed necessary for North Creek, there are some BMPs that could be implemented to address the relatively small anthropogenic impacts observed in the watershed. Implementation of BMPs in North Creek would also lead to reductions observed downstream in the Virgin River main-stem. Most sources in the North Creek watershed are natural, and therefore the only implementation recommendation is to limit the impact caused by livestock and ATVs.

Sources of pollutant loadings:

- Natural hill-slope erosion
- Scattered agricultural practices
- Limited livestock in stream
- ATV use
- Off channel ponds

Table 6-17. BMPs recommended for the North Creek watershed.

Practice Number	Practice Name	Intensity Level
120	Grazing Management	Passive Management
210	Exotic Removal	Active Management
220	Fencing	Active Management
NA	Limits on ATV Use	Passive Management

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7.0 MONITORING

DWQ will continue to monitor the water quality in the Virgin River watershed over the next several years as part of ongoing watershed monitoring program. These data will allow for the periodic re-evaluation of the implementation strategies, milestones, and goals identified in this TMDL and the accompanying watershed management plan. The existing stations are considered adequate for assessing water quality for the various portions of the watershed. The frequency of sampling (approximately monthly at the most significant stations) should be continued.

Various other data could be obtained to allow for a more complete assessment of current water quality conditions and to better quantify the load from specific sources. These additional data include:

- Efforts should be made to sample the volume and characteristics of irrigation return flows to better estimate their impact on in-stream water quality. Representative locations should be chosen so that data are available for the various irrigation, crop, and soil types.

- Photo monitoring sites can be utilized for future comparisons of changes in geomorphology, streambanks, riparian conditions, flow levels, and salt crusts. The existing work completed by the Utah Water Research Laboratory is an excellent foundation for completing such an assessment.

- Additional aerial photo analysis can be utilized to monitor the riparian corridor health, the composition of the vegetation in the riparian corridor, the amount of invasive Tamarix, and to track geomorphic changes over time.

- Installation of bank erosion pins, and follow-up measurements of the pin, could be used to track stream bank erosion over time for areas of the watershed with the most severe bank erosion problems.

- Installation of scour chains downstream of in-stream disturbances would allow for tracking of deposition and scour and the net gain or loss of sediment in the stream bottoms.

- Additional stream channel cross sections can be collected at certain sites to track channel morphology changes over time.

- Permanent follow-up monitoring sites can be selected depending upon the location of future implementation projects and sampled to establish simple trend analysis, and gauge BMP effectiveness.

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8.0 PUBLIC PARTICIPATION

In Utah, the development of TMDLs is integrated within a larger watershed management framework that emphasizes a common-sense approach aimed at protecting and restoring water quality. Key elements of this approach include:

- Water quality monitoring and assessment
- Local stakeholder leadership
- Problem targeting and prioritization
- Integrated solutions that coordinate multiple agencies and interest groups.

Each of these key elements has been addressed through this TMDL project. The technical analysis conducted for the TMDL was based on the extensive water quality monitoring data collected by DWQ and others. The Virgin River Watershed Advisory Committee has been involved with the development of the TMDL through their participation in several meetings at key junctures in the project:

- Project Kickoff Meeting on June 11, 2002
- Field Survey Meeting on October 10, 2002
- Key Issues Public Meetings on July 9th and 10th, 2003
- TMDL Overview and Status Report Meeting on October 27, 2003

Members of the Committee, and other watershed stakeholders, have also been involved with the development of the TMDL through their participation in efforts to compile available information. Stakeholders that have provided information critical to the successful development of this TMDL include the following:

- Washington County Water Conservancy District
- Utah Water Research Laboratory
- Zion National Park
- Ash Creek Special Service District
- City of St. George
- Five County Association of Governments

Implementation strategies for the TMDL will be incorporated into the Virgin River Watershed Management Plan, which has been developed in tandem with the TMDL. The Committee, composed of representatives from the following agencies, will be primarily responsible for targeting site-specific management practices and prioritizing solutions.

- Washington County Water Conservancy District
- Dixie National Forest
- Bureau of Land Management
- City of St. George
- Town of Springdale
- Washington County
- U.S. Natural Resources Conservation Service
- Dixie Soil Conservation District
- Kane County
- LaVerkin Bench Canal Company
- Town of Rockville
- City of Ivins
- Ash Creek Special Service District
- Zion National Park
- Utah Department of Natural Resources
- St. George Washington Canal Company
- Iron County
- City of Santa Clara
- Shivwits Band Paiute Indian Tribe
- City of LaVerkin

- Five County Association of Governments
- City of Hurricane
- Kane County Water Conservancy District
- U.S. Forest Service
- Virgin River Land Preservation Association
- People for the USA
- City of Washington
- Utah Division of Water Resources
- Virgin River Program
- Utah Division of Water Rights

The draft TMDL report was also made available by DWQ for public comment. The comments that were received, and responses, are summarized in Appendix C.

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APPENDIX A: BEAVER DAM WASH VEGETATION ANALYSIS

The Beaver Dam Wash watershed occupies portions of Arizona, Nevada, and Utah (Figure A-1). Drainage for the watershed is provided by the Beaver Dam Wash, which originates in Utah and flows south through portions of Nevada and Utah before discharging into Arizona. Beaver Dam Wash, from Motoqua to the Utah/Nevada state line, is listed on Utah's 2002 303(d) list as impaired for temperature for the beneficial use of cold water game fish and other cold water aquatic life (3A).

Figure 1. Location of the Beaver Dam Wash watershed.

When investigating water temperature impairments, it is important to characterize land use/land cover and vegetative cover in the watershed and determine how these factors influence water temperature. The density and type of vegetative cover, especially in the riparian corridor, have a significant impact on stream water temperatures. Riparian corridors containing dense or tall vegetation are efficient in providing shade and preventing direct sunlight from heating stream water. Conversely, stream corridors which are dominated by shrub species or thin vegetative cover are more susceptible to the effects of direct sunlight and have naturally higher temperatures. This is estpecially true in the dry Southwest, where ambient air temperatures are high throughout the summer with lots of direct sunlight during the day..

The effects of a poorly shaded riparian corridor can be exacerbated by shallow depths, low flow, and wider stream channels. In shallow, low flow streams, direct sunlight can increase water temperature more rapidly. Also, as stream channel width increases, the surface area of the stream increases which allows more sunlight to contact stream surfaces. Elevated water temperatures can also result from excessive sedimentation, siltation, and stream embeddedness.

Land Use and Land Cover in the Beaver Dam Wash Watershed. General land use and land cover data for the Utah portion of the Beaver Dam Wash basin above Motoqua were extracted from the Multi-Resolution Land Characterization (MRLC) database (MRLC, 1992) and are shown in Figure A-2 and Table A-1. This database was derived from satellite imagery taken during the early 1990s and is the most current detailed land use data known to be available. Each 30-meter by 30-meter pixel contained within the satellite image is classified according to its reflective characteristics.

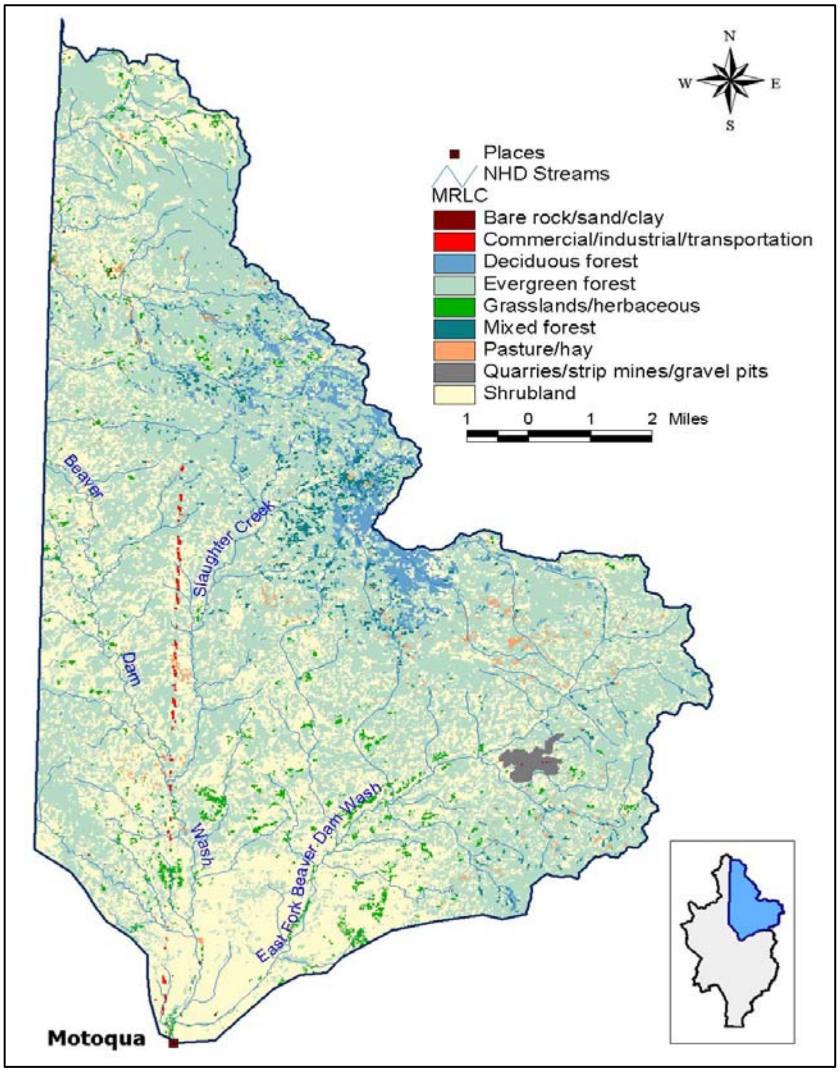

Figure A-2. MRLC land use/land cover in the Beaver Dam Wash watershed.

MRLC land use for the Beaver Dam Wash is dominated by evergreen forest and shrubland, each contributing to appoximately 53 percent and 38 percent of total land cover, respectively. Approximately 3 percent of the watershed is occupied by deciduous forest, while 1.4 percent is in mixed forest. All remaining land uses individually account for less than one percent of total land cover. A very small portion of the watershed is classified as commercial/ industrial/transportation and quarries/strip mines/gravel pits. The commercial/industrial/ transportation land cover is attributed to a powerline transecting the watershed.

Table A-1. MRLC land use/land cover in the Beaver Dam Wash watershed.

Land Use/Land Cover	Area Hectares	Area Acres	Percent
Evergreen forest	19,191	47,401	53.75
Shrubland	13,856	34,224	38.81
Deciduous forest	1,042	2,574	2.92
Grasslands/herbaceous	616	1,521	1.72
Mixed forest	507	1,253	1.42
Pasture/hay	286	707	0.80
Quarries/strip mines/gravel pits	147	362	0.41
Commercial/industrial/transportation	52	130	0.15
Bare rock/sand/clay	5	13	0.01
Total	**35,703**	**88,186**	**100.00**

Vegetative Cover. Vegetative data were gathered from the Gap Analysis Project (GAP) completed for the state of Utah. The GAP Analyses is a nation-wide program conducted under the guidance of the USGS for the purpose of assessing the extent of conservation of native plant and animal species. Since an important part of the analyses is the identification of habitat, detailed vegetative spatial data are available for states that have completed their analyses. Like the MRLC data, the spatial database for Utah was derived from satellite imagery taken during the early 1990s. However, the GAP vegetative classification is more detailed than MRLC; the GAP data includes vegetative species such as juniper, rather than general land cover classes like evergreen forest.

Juniper, oak, and blackbrush dominate vegetative cover in the watershed and represent 69.36 percent, 18.03 percent, and 4.89 percent of the land area, respectively (Table A-2). Juniper vegetation, as defined by the GAP analysis, is principally juniper, and may include various associated tree and shrub species such as pinyon, mountain mahogany, sagebrush, and blackbrush (Figure A-3). In addition, lowland riparian vegetation accounts for 2.17 percent of vegetation and occurs in isolated areas along stream corridors below 5500 feet above mean sea level. Lowland riparian may include fremont cottonwood, salt cedar, netleaf hackberry, velvet ash, desertwillow, sandbar willow, and squawbush vegetation (Figure A-4). With the exception of introduced crop species such as alfalfa (which is very limited), the majority of vegetation in the watershed is native to the watershed and occurs in its natural state. Figure A-5 provides a spatial distribution of vegetative cover in the Beaver Dam Wash basin.

Table A-2. GAP vegetative cover in the Beaver Dam Wash watershed.

Vegetative Cover	Area Hectares	Area Acres	Percent
Juniper	24,761	61,160	69.36
Oak	6,439	15,904	18.03
Blackbrush	1,747	4,315	4.89
Pinyon-Juniper	826	2,040	2.31
Lowland Riparian	776	1,917	2.17
Sagebrush/Perennial Grass	435	1,074	1.22
Mountain Shrub	402	993	1.13
Mountain Riparian	230	568	0.64
Grassland	85	210	0.24
Total	**35,701**	**88,181**	**100.00**

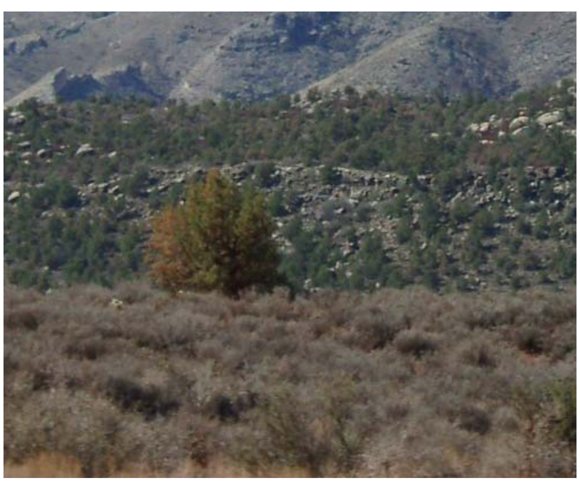

Figure A-3. Juniper and sagebrush vegetation in the Beaver Dam Wash watershed.

Figure A-4. Lowland riparian vegetation including: fremont cottonwood, cattails, and sandbar willow.

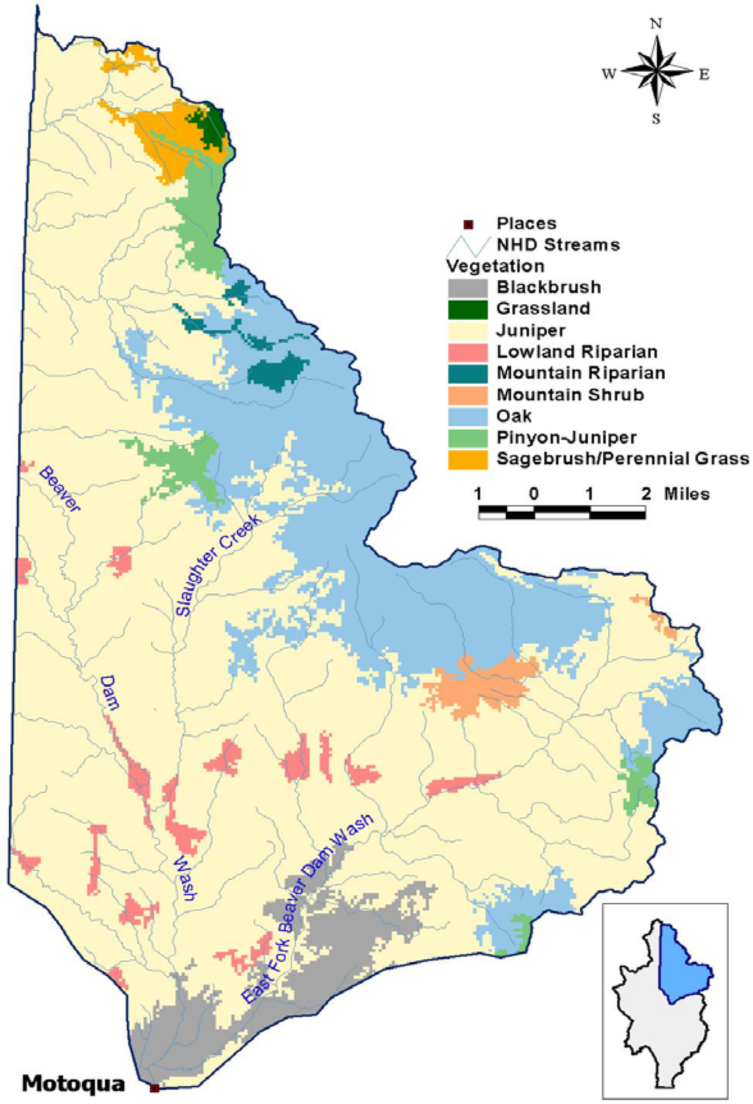

Figure A-5. GAP vegetative cover distribution in the Beaver Dam Wash watershed.

Riparian Vegetation. Since riparian vegetation has more of an effect on stream temperature than non-riparian vegetation, GAP vegetative data for the Beaver Dam Wash riparian corridor were extracted and analyzed. To account for variability in the riparian corridor width, the Beaver Dam Wash main stem riparian corridor was assumed to extend 150 meters from each side of the stream channel. The resolution of the GAP data makes it difficult to perform an analysis on a smaller width. The riparian corridor was simulated in Arc View GIS by buffering the Beaver Dam Wash main stem to a distance of 150 meters. GAP vegetative data were then extracted using spatial overlay techniques. Figure A-6 displays vegetative cover in the riparian corridor.

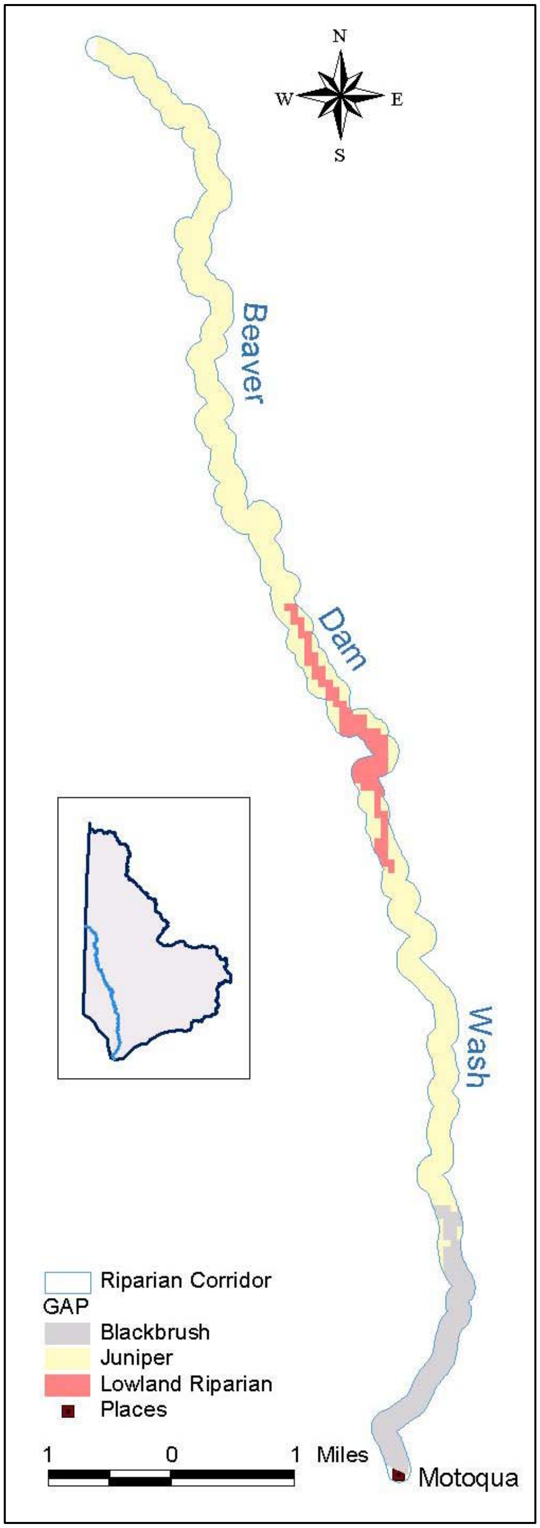

Figure A-6. Beaver Dam Wash main stem riparian corridor vegetative cover.

Analysis of GAP vegetative cover demonstrates that exceptionally high quality vegetation exists in the Beaver Dam Wash riparian corridor and vegetation type, density, and distribution are consistent with vegetation throughout the southwestern region. A field visit confirmed that vegetative cover is also normally distributed among all age classes. In addition, the riparian corridor is stable, supports a healthy vegetative environment, and is properly functioning. The stream itself showed no signs of excessive sedimentation (e.g., braided channel, siltation, embeddedness) and therefore is not widening and shallowing, which would also contribute to high temperatures.

Figure A-6 demonstrates that roughly 90 percent of the riparian corridor is composed of juniper and blackbrush vegetation. Juniper vegetation usually occurs in low densities and does not provide significant shade to the stream (Figure A-7). Blackbrush is the dominant vegetation in the lower reach of Beaver Dam Wash and consists of blackbrush and its associated species, such as spiny hopsage, mormon tea, shadcale, snakeweed, turpentine bush, creosote, yucca, and cacti. These species also provide little shade to the stream (Figure A-8).

A small area in the middle portion of the Beaver Dam Wash is occupied by lowland riparian vegetation. This vegetation class provides better quality shade due to the presence of fremont cottonwood, desert willow, and sandbar willow, which have relatively thick canopies and are densely populated in localized areas along the stream banks (Figures A-9 and A-10). However, the most-dense portions of lowland riparian vegetation are often located away from the streambank and do not over-reach the stream to provide direct protection from the mid-day sun (Figures A-11 and A-12). Figure A-12 also shows dense vegetation on the stream bank that shades the stream from the morning and evening sun but does not provide protection from exposure to the mid-day sun.

Figure A-7. Low-density juniper vegetative cover and associated shrub species provide little shade to the majority of the Beaver Dam Wash.

Figure A-8. Blackbrush vegetation sparsely populated with fremont cottonwood.

Figure A-9. Lowland riparian vegetation in the Beaver Dam Wash including fremont cottonwood and sandbar willow. Shade is provided during the morning and evening.

Figure A-10. Riparian vegetation composed of fremont cottonwood and sandbar willow.

Figure A-11. Uneven distribution of lowland riparian vegetation allows for exposure to direct sunlight.

Figure A-12. Dense lowland riparian situated away from the stream bank is not efficient in protecting the stream from direct sunlight.

Temperature Data. Temperature data were collected in half-hour increments at five sites on the Beaver Dam Wash from Motoqua upstream into Nevada for the period from July 8, 2002 to September 9, 2002. Table A-3 and Figure A-1 show the period of record and station locations on the Beaver Dam Wash. Since ambient air temperatures are at their annual maximum during the month of July in this portion of the watershed, sampling during the month of July represents water temperatures during critical conditions.

Table A-3. Inventory of water temperature sampling stations and data availability.

	Data Availability	
Station Name	**July 9- July 30**	**July 30-Sept. 9**
BDW @ Motoqua	Yes	No
BDW @ lower site below Sucker (near ledge)	No	Yes
BDW @ upper farm (mid stream)	No	No
BDW mid station below road	No	Yes
BDW @ end of road from bottom	No	Yes
BDW @ campground area below Reservoir	Yes	No
BDW above State park below bridge	Yes	Yes

Figures A-13 through A-18 show all sampling data collected in July and demonstrate trends in water temperature for the sampling period as well as semi-hourly statistics (average, minimum, maximum, and the 25^{th}-75^{th} quartiles) for each sampling station. Water temperatures fluctuate throughout the course of the day reaching their minimum between 7AM and 9AM for the three sampling stations. Maximum temperatures are observed at 3PM in the Motoqua site, at approximately 5PM at the Campground site, and between 5PM and 7:30PM at the Beaver Dam Wash above Nevada State Park.

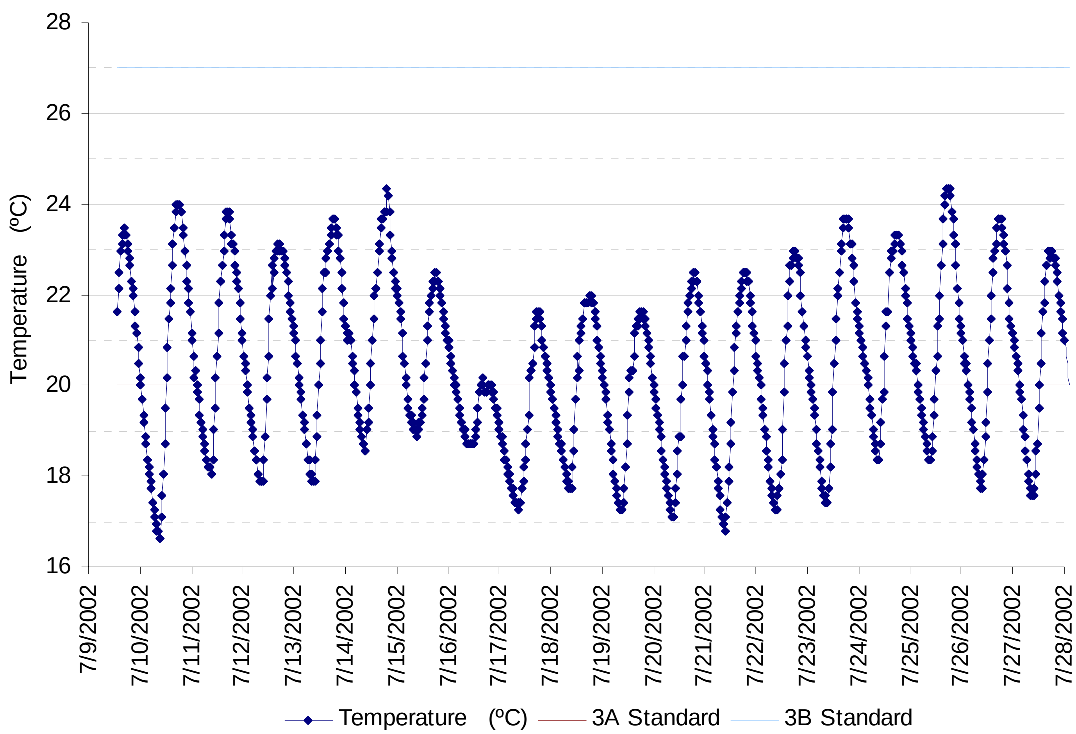

Figure A-13. All temperature observations and daily trends for the Beaver Dam Wash above the Nevada State Park sampling station.

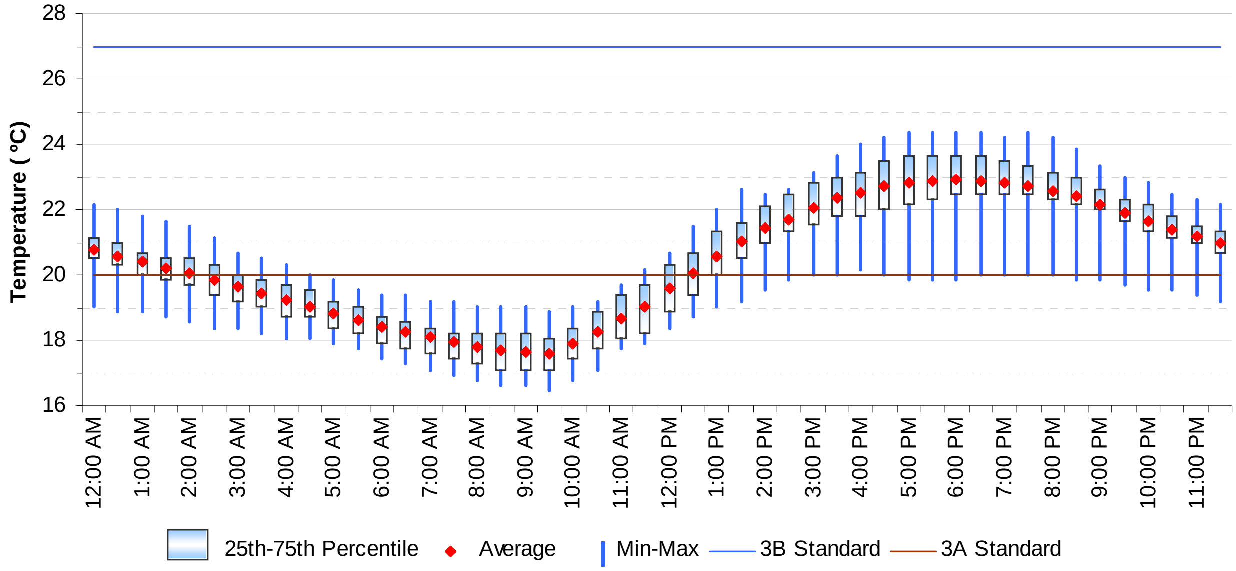

Figure A-14. Hourly trends in temperature samples for the Beaver Dam Wash at the Nevada State Park sampling station.

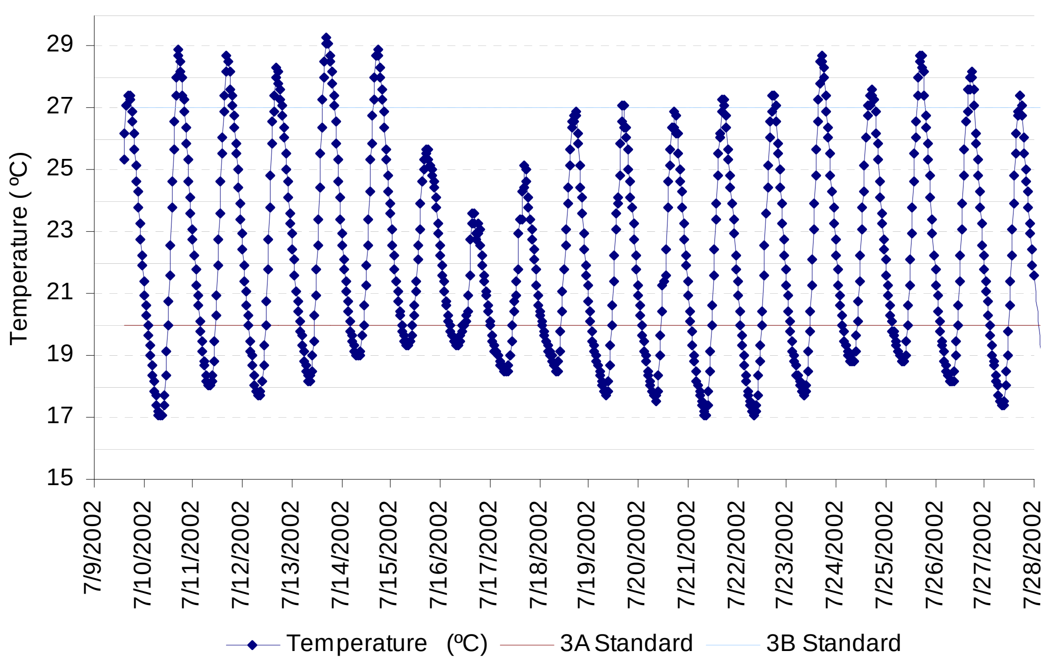

Figure A-15. All temperature observations and daily trends for the Beaver Dam Wash at the Campground sampling station.

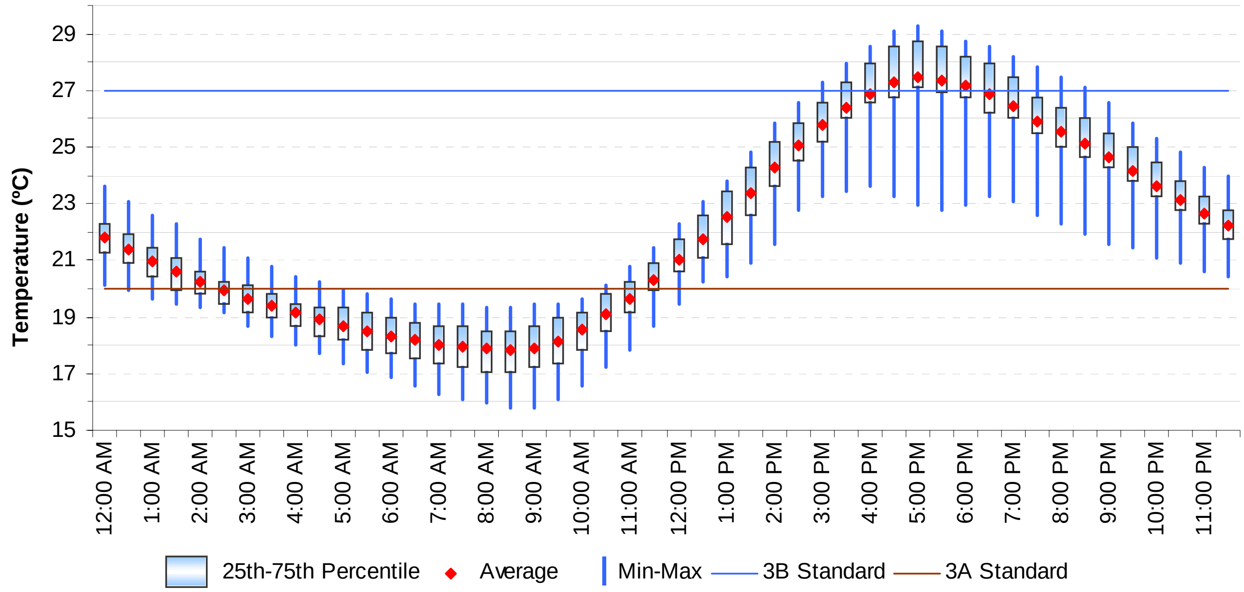

Figure A-16. Hourly trends in temperature samples for the Beaver Dam Wash at the Campground sampling station.

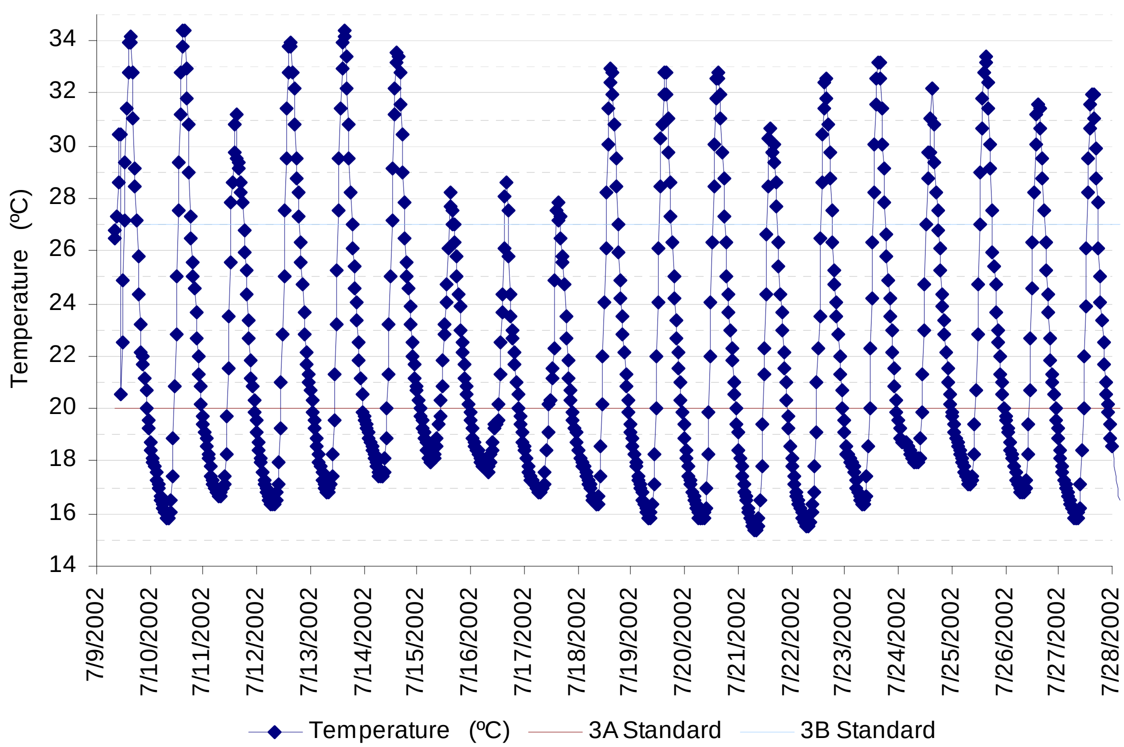

Figure A-17. All temperature observations and daily trends for the Beaver Dam Wash at the Motoqua sampling station.

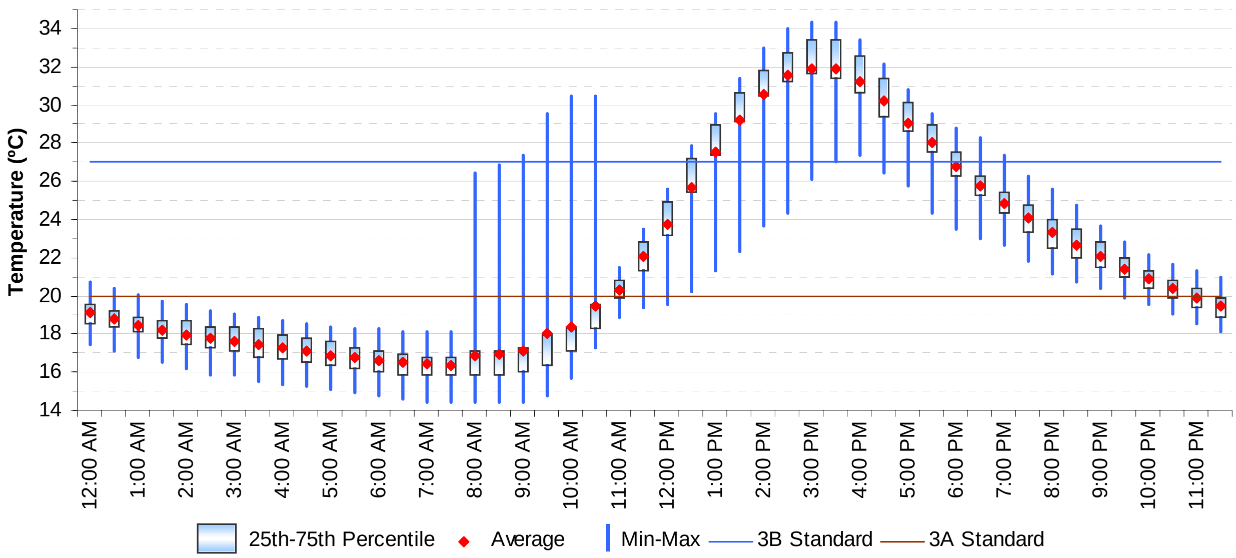

Figure A-18. Hourly trends in temperature samples for the Beaver Dam Wash at the Motoqua sampling station.

Temperature data from all sites were compared to the proposed 3B standard (27 ºC) to estimate the probability of exceedance. Table A-4 demonstrates zero 3B temperature exceedences for the Beaver Dam Wash above the Nevada State Park, while 10 percent and 21 percent exceedences were observed at the Campground (Figure A-15 and Figure A-16) and Motoqua (Figure A-17 and Figure A-18) sampling stations in the month of July, respectively. It is important to note that temperature samples for the three sites are only for the month of July and represent critical conditions for water temperature. If data were available year-round water temperatures would likely exceed the 3B standard less than 10 percent of the time. Water temperatures for the period from July 30, 2002 to September 9, 2002 are lower than samples for July 9, 2002 to July 30, 2002. In addition, overall percent exceedences are lower for the second sampling event.

Table A-4. Percent exceedence of the 3B temperature standard (27 ºC).

	Percent Exceedence	
Station Name	**July 9- July 30**	**July 30-Sept. 9**
BDW @ Motoqua	21	No Data
BDW @ lower site below Sucker (near ledge)	No Data	9
BDW @ upper farm (mid stream)	No Data	No Data
BDW mid station below road	No Data	12
BDW @ end of road from bottom	No Data	7
BDW @ campground area below Reservoir	10	No Data
BDW above State park below bridge	0	1

A GIS analysis combined with a field inspection of the Beaver Dam Wash watershed and a review of the available temperature data demonstrates that the vegetation present in the watershed, and especially along the streambank, is of high quality and naturally occurring. Approximately 90 percent of the riparian corridor is vegetated with juniper and blackbrush and their associated species, which provide little shade. Although some portions of the corridor include shade-providing lowland riparian vegetation, this cover is not dense or uniform enough to significantly lower water temperatures. Furthermore, the naturally shallow depths and low flows of the stream also contribute to elevated water temperatures. In conclusion, the presence of high quality riparian vegetation and the absence of other temperature controlling factors in the Beaver Dam Wash watershed suggest that warm water temperatures are natural and the cold water beneficial use designation is not appropriate.

APPENDIX B: IMPLEMENTATION APPENDIX

APPENDIX C: RESPONSIVENESS SUMMARY

COMMENTER: WASHINGTON COUNTY WATER CONSERVANCY DISTRICT

Comment: In general, there are concerns about the causes of impairment. This report does not adequately analyze the springs along the basin and Pah Tempe in particular, TDS impacts, selenium impacts, boron in the water and increases in the temperatures in river corridors below Pah Tempe. These need to be addressed and potential remedies specified.

Response: The TMDL report addresses all of the causes of impairment that were identified by DWQ on the section 303(d) list. The effect of Pah Tempe on downstream TDS conditions in the Virgin River was analyzed in some detail (pages 86 to 89) and resulted in the recommendation of a site-specific criterion due to the naturally high concentrations. A selenium TMDL was developed for the Santa Clara River. Springs were included in the quantification of natural loads of both of these pollutants. The impacts of high TDS and selenium concentrations on the relevant designated uses (agriculture and aquatic life, respectively) were summarized in section 2.2.1 and 2.2.4. Mitigating these impacts is based on reducing loads to meet water quality standards and potential remedies (i.e., best management practices) were suggested in section 6 (implementation).

Boron and temperature were not identified as causes of impairment in the Virgin River and were therefore beyond the scope of the TMDL.

Comment: Pg. 29 ***Sand and Gravel Mining:*** *The solution to the problem is not this simple. The reservoir has historically had huge sediment problems due to deposition of sediment from the town of Gunlock and further upstream. Before the sand and gravel operation, the Santa Clara River was unable to handle an ordinary flood due to previous sedimentation. Far from Acausing increased stream channel erosion and siltation downstream,@ the Gunlock sand and gravel operation helps return the stream flow to a natural gradient and helps protect the town of Gunlock. We do not believe that there is any basis for your conclusions on this operation or that the operation results in additional sediment in the reservoir. Rather, it works to keep the sediment out of the reservoir and thus retain sufficient capacity to allow the stream flows to reach the reservoir instead of causing problems to personal property in the Gunlock area.*

Response: Other comments were received alluding to the fact Gunlock Reservoir has historically had sediment problems and we will therefore modify our original discussion of the role the sand and gravel mining has had on contributing to the filling of the reservoir. However, it is still our opinion that the sand and gravel operation has already or will eventually result in a change to the natural geomorphology of the river. Although the operation is removing some sediments from the stream, it is also changing the natural pattern and profile of the channel. It is generally accepted within the scientific community that such changes will result in the channel attempting to re-establish equilibrium with itself during bankfull flood events. Such re-establishment is likely to result in increased suspended sediment loads as the channel migrates laterally and increased bank erosion and bed scour occurs.

Comment: Pg. 37 ***Irrigation Return Flows:*** *Frank Williams at BYU should be consulted to discuss the impacts of flood irrigation especially in the Washington Fields area. Leaching is required in order to use the high TDS for irrigation purposes and it requires significant amounts of additional water. However, there is a balance in what is being applied and what is being carried off. Irrigation is not a major contributor to the increase in TDS or TP associated with returned irrigation water.*

Response: We understand that leaching is required in the Washington Fields area in order to be able to use the high salinity water for agriculture. We used typical leaching factors published by Utah State University in our analysis of the volume of water used for irrigation. We also used evapotranspiration rates (also from Utah State University) and estimates of transport and application inefficiencies to estimate the total volume of returned irrigation water. We therefore are reasonably confident in our estimate of the volume of returned irrigation water. Unfortunately, few data are available on the concentration of TP and TDS in irrigation return water. However, it is highly unlikely that these values are zero and therefore some load is associated with irrigation return flows. We used best professional judgment and chose TP and TDS concentrations based on the limited available data in the watershed and previous studies in Utah and elsewhere.

Comment: Pg. 47. ***North Creek of the Virgin River:*** *The Virgin River has always been a high TDS river. It is our belief that this is a result of the soils that the riverbed crosses and the contaminants of some of the springs that carry a high TDS concentration. We have watched specific springs over the years and they are much higher in TDS than the Virgin River.*

Response: We agree that both North Creek and the Virgin River are naturally high in TDS due to a number of factors including alluvial soils, springs, and erosive shale in the watershed. Site-specific standards are therefore being proposed that are much higher than the statewide TDS standard of 1,200 mg/L.

Comment: Pg. 50. ***Cattle Grazing Photo:*** *This photo was taken on private property and not within Zion National Park.*

Response: We will modify the caption of this photo to read "Cattle grazing in the headwaters of North Creek."

Comment: Pg. 52. ***Anthropogenic Sources:*** *Seems there is an inordinate amount of attention given to livestock grazing and not nearly enough given to the impact of humans on the land (ATVs, camping, etc.), which may have a significantly higher impact than cattle grazing in the North Creek drainage.*

Response: We will list ATVs and camping as additional anthropogenic sources in the North Creek drainage. The point of this analysis, however, is that the total impact of anthropogenic activities is limited.

Comment: Pg. 75. ***TDS in the Virgin River:*** *Does not address that the primary and most significant source of TDS is Pah Tempe Springs. Pah Tempe has an impact on everything below Quail Creek Diversion/VR System.*

Response: The impact of Pah Tempe Springs is acknowledged in some detail on pages 86 to 89. Furthermore, the natural load from Pah Tempe is a significant component of the site-specific criteria that has been derived for the Virgin River from Pah Tempe to the state line.

Comment: Pg. 105. Do not agree. See ***Sand and Gravel Mining*** *above (Pg. 29).*

Response: See response above.

Comment: Pg. 118 ***Stretch from Gunlock Reservoir:*** *There is an inordinate amount of analysis of current livestock loads. The impact of livestock is overstated and the impact of the recreational user (ATVers, camper, hiker, etc.) is understated. There is no analysis as to the early historic conditions of the area. The watershed is in much better condition today than it has been in over a century and this can be backed up with data. The Old Spanish Trail lies in this area. Thousands and thousands of head of cattle were herded from Mountain Meadow to the west coast in the early 1800's. The report states that* *there are now 750 cattle grazing in the watershed above Gunlock. That seems a little high. If there actually are 750 cattle, it is on a seasonal basis and not year round.*

Response: The objective of developing a TMDL is to determine whether waterbodies are meeting current water quality standards. Historic conditions are important for providing perspective on the natural conditions of a system, but are not the basis for the TMDL. In other words, the fact that current conditions are better than historic conditions is not sufficient to keep a TMDL from being developed. The ultimate goal is meeting water quality standards. We will clarify that the 750 cattle includes the number of animals above Baker Dam reservoir.

Comment: Pg. 135. ***Fort Pierce Wash:*** *There is no adequate analysis re of water quality in Fort Pierce Wash.*

Response: Table 5-19 summarizes the available TDS data for Fort Pierce Wash and indicates that average TDS concentrations are above the statewide standard of 1,200 mg/L but below the proposed site-specific standard of 2,360 mg/L. Table 5-26 also presents the annual load of TDS from Fort Pierce Wash at approximately 13,000,000 kg/yr, or 7 percent of the total load in the Virgin River below the first narrows. Section 6 includes a list of BMPs to improve water quality in the Fort Pierce Wash watershed.

Comment: Pg. 137. ***Washington Fields Diversion - Quail Creek Reservoir:*** *The impact of salt cedar on the watershed needs more analysis. Also, there are no studies that document that the Hurricane sewer lagoons are a problem. There has always been a series of springs below the Hurricane bridge before the sewer lagoons. I am not aware of any studies documenting the increase in springs as a result of seepage.*

Response: We will add additional discussion of the impacts of salt cedar to the TMDL report, although there are few data quantifying the load of salt from these trees. More information is available regarding the quantities of water they consume. We will clarify that the source of the seepage near the Hurricane lagoons is unknown.

COMMENTER: HURRICANE CITY

Comment: In reviewing the document and realizing it's potential impact on the Washington County area, I have some concerns about the general format of the study and the document. In every meeting I attended during this study, comments have been made concerning the importance of taking into consideration the naturally occurring materials that contribute to the water quality of the Virgin River. This draft document refers only minimally to this condition. Its main focus is on unproven and potential sources of impact as if, by inference, these are the causes of all the water quality concerns.

Response: The total loads, including from natural sources, have been quantified during the development of the TMDL and are reported in the existing source load summary tables. These natural loads include land erosion and groundwater springs and the naturally high loads of TDS were the major reasons site-specific criteria were adopted for North Creek and the Virgin River below Pah Tempe Springs.

Comment: "During the field assessment it was noted all agricultural fields in the Virgin River watershed were irrigated by some method." This appears to meet no scientific or logical basis for study. Just how did they expect agricultural fields to be maintained as agricultural fields in the Virgin River watershed?

Response: This statement was merely providing a background description of conditions in the watershed for readers who might not be familiar with the area. The TMDL report has a potentially wide audience, including readers who might not realize that agriculture in the watershed would not be possible without irrigation.

Comment: On page 22 there is a statement that visual observation revealed no leakage from the Rockville wastewater lagoons. In direct contrast, the observation on the Hurricane Lagoons indicates they "are suspected to be leaking". Is this suspicion based on observation, testing, or some other scientific study method?

Response: Groundwater seepage directly below the Hurricane Lagoons was observed during the site visit and was initially attributed to the lagoons. The text in the final report has been changed to state that the source of the seepage is unknown.

Comment: On page 25 the statement about septic systems in Pine Valley that "could be" contributing to the TP in the Santa Clara River is not backed up by any scientific data supporting this supposition.

Response: Unfortunately, conducting dye studies of septic systems in the Pine Valley area was outside the scope of the current study. Similarly, no information was available regarding the proportion of systems that are currently failing. However, previous research conducted in many areas of the country indicates that the probability of septic systems contributing TP loading is greatly enhanced as the distance to surface waters decreases. Previous research also documents that some portion of septic systems almost always fail due to poor soil conditions and/or inadequate maintenance. The approach used to estimate the potential magnitude of TP loads in the Pine Valley area is consistent with numerous other TMDLs conducted throughout the country.

COMMENTER: U.S. FISH AND WILDLIFE SERVICE

Comment: I don't remember any mention of farm ponds and oil and gas ponds in the TMDL as potential sources of TDS and selenium. Were these quantified and accounted for in the TMDL?

Response: Stock and oil/gas ponds were not quantified separately in the TMDL because they were not considered significant sources of TDS or selenium relative to the other identified sources.

Comment: I have concerns with the methods used for setting site-specific criteria for North Creek (e.g., using the 90th percentile), though I have no specific recommendations. This is based on several items. First, data presented in Figure 5-4 and Table 5-3 do not indicate significant exceedances, but rather it appears that TDS concentrations are near the standard. Second, when flows are above 2 cfs it appears that TDS concentrations are acceptable. Third, when flows are below 2 cfs, there is significant variability in TDS concentrations; however, sample size is small for the flow percentiles 1-10 and 20-30, and it is possible that these may significantly skew the distribution. Fourth, when flows are less than 1 cfs, agricultural use seems unlikely. Finally, the TMDL did not mention if there are any diversions (e.g., for ag). The proposed standard of 2035 mg/L seems kind of high; however, this is close to the stock watering standard, and it in theory should only be an issue at very low flows. I just hope that this new standard does not encourage management practices that will increase TDS in North Creek.

Response: The proposed site-specific criteria certainly is certainly not intended to encourage management practices that will increase TDS in North Creek. Instead, the decision to propose a site-specific standard is based primarily on the lack of anthropogenic sources in this drainage and therefore a limited ability to change management practices to reduce existing concentrations. The commenter is correct in pointing out that exceedances of the 1,200 mg/L standard only occur during very low flow events when agricultural use is unlikely.