Prepared in cooperation with the Colorado River Basin Salinity Control Forum

# Discharge, Water Quality, and Native Fish Abundance in the Virgin River, Utah, Nevada, and Arizona, in Support of Pah Tempe Springs Discharge Remediation Efforts

By Matthew P. Miller, Patrick M. Lambert, and Thomas B. Hardy

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# Conversion Factors and Water-Quality Units

Inch/Pound to SI

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| mile (mi) | 1.609 | kilometer (km) |
| | Flow rate | |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| | Mass | |
| ton per year (ton/yr) | 0.9072 | metric ton per year |

SI to Inch/Pound

| Multiply | By | To obtain |
|---|---|---|
| | Area | |
| square meter ($m^2$) | 10.76 | square foot ($ft^2$) |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

# Discharge, Water Quality, and Native Fish Abundance in the Virgin River, Utah, Nevada, and Arizona, in Support of Pah Tempe Springs Discharge Remediation Efforts

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## Abstract

Pah Tempe Springs discharge hot, saline, low dissolved-oxygen water to the Virgin River in southwestern Utah, which is transported downstream to Lake Mead and the Colorado River. The dissolved salts in the Virgin River negatively influence the suitability of this water for downstream agricultural, municipal, and industrial use. Therefore, various remediation scenarios to remove the salt load discharged from Pah Tempe Springs to the Virgin River are being considered. One concern about this load removal is the potential to impact the ecology of the Virgin River. Specifically, information is needed regarding possible impacts of Pah Tempe Springs remediation scenarios on the abundance, distribution, and survival of native fish in the Virgin River. Future efforts that aim to quantitatively assess how various remediation scenarios to reduce the load of dissolved salts from Pah Tempe Springs into the Virgin River may influence the abundance, distribution, and survival of native fish will require data on discharge, water quality, and native fish abundance. This report contains organized accessible discharge, water quality, and native fish abundance data sets from the Virgin River, documents the compilation of these data, and discusses approaches for quantifying relations between abiotic physical and chemical conditions, and fish abundance.

## Introduction

The Virgin River is home to six native fish species. Two of these species, the woundfin (*Plagopterus argentissimus*) and the Virgin River chub (*Gila seminuda*), are federally listed as endangered species. The Virgin spinedace (*Lepidomeda mollispinis*), while not federally listed, was proposed for listing as an endangered species in 1994. The other native fish species in the Virgin River include the speckled dace (*Rhinichthys ocsulus*), the desert sucker (*Catostomus clarki*), and the flannelmouth sucker (*Catostomus latipinnis*). The abundance and distribution of these fish in the Virgin River has been studied extensively. As with all organisms, the ability of the native fish of the Virgin River to survive in a given area is dependent on the physical, chemical, and biological conditions in the river. Specifically, each species can only survive in a specific range of habitat (e.g. discharge, temperature, dissolved solids, and dissolved oxygen) conditions.

Although many studies have quantified the abundance, distribution, and habitat requirements of native fish species in the Virgin River, the direct links between changing water quantity/quality conditions and native fish survival in the Virgin River are less clear. One source of water that influences the habitat conditions that the native fish species of the Virgin River depend on is Pah Tempe Springs, which discharge hot, saline, low dissolved-oxygen water to the Virgin River. Pah Tempe Springs discharge approximately 95,000 tons of dissolved solids annually to the Virgin River (Gerner, 2008) that are transported downstream and eventually discharged into the Colorado River. These dissolved salts negatively influence the suitability of this water for downstream agricultural, municipal, and industrial use. Recent studies by the U.S. Geological Survey (USGS) have estimated that removal of the dissolved solids discharged from Pah Tempe Springs would initially decrease the dissolved-solids load in the Virgin River at Littlefield, Arizona by 66,700 to 70,300 tons per year (tons/yr). In turn, the amount of salt moving into the Littlefield Springs system as a result of seepage from the Virgin River would be reduced, and the dissolved-solids load to the Virgin River at Littlefield, Arizona is predicted to decrease by an additional 20,600 to 24,200 tons/yr within 27 years (estimated lag time from river seepage) of mitigation (Gerner and Thiros, 2014).

On the basis of these estimated salinity load reductions, the Bureau of Reclamation Colorado River Basin Salinity Control Program (Program) has recommended assessing the feasibility and impacts of Pah Tempe Springs load removal, including the effects of mitigation on downstream Virgin River discharge, chemistry, and ecology. Specifically, managers would like to be able to answer the overarching question, "How will various remediation scenarios to reduce the load of dissolved solids from Pah Tempe Springs into the Virgin River influence the abundance, distribution, and survival of native fish?" The ability to quantitatively predict how future changes in water quantity and quality conditions in the Virgin River will influence native fish abundance, distribution, and survival would be an asset to Program managers charged with assessing the feasibility of mitigating the salinity load of Pah Tempe Springs and the effects of mitigation on the ecology of the Virgin River. A baseline set of discharge, water quality, and native fish abundance data are required to provide a foundation from which future models or assessments can be developed to quantitatively address the aforementioned overarching question.

## Purpose and Scope

As a necessary first step towards quantifying the impacts of potential Pah Tempe Springs remediation scenarios on native fish, we have produced organized accessible discharge, water quality, and native fish data sets as eight separate appendixes. This report documents the compilation of data describing water quantity and quality characteristics that are anticipated to change in the Virgin River as a result of Pah Tempe Springs remediation scenarios, and that are known to influence native fish survival (i.e. discharge, temperature, dissolved oxygen, and total dissolved solids). Existing data on the abundance and distribution of native fish in the river are also documented. This work builds upon extensive work that has already been completed on native fish abundance and distribution, and (or) water-quality conditions as part of the Virgin River Resource Management and Recovery Program (*http://www.virginriverprogram.org*), and reported in publications by Utah State University (USU; Hardy and others, 2003), the Utah Department of Natural Resources (UTDNR; Fridell and Morvilius, 2005; Bennion and Fridell, 2006), and the U.S. Fish and Wildlife Service (USFWS; U.S. Fish and Wildlife Service, 1994). These previous water quality and (or) native fish studies in the Virgin River have not systematically compiled water quality and native fish abundance data that can be used to assess the impacts of Pah Tempe Springs remediation on native fish. This scope of work is unique in that it does systematically compile, and document the compilation of, fish abundance and distribution data using a pre-selected set of water-quality variables that are expected to change as a function of remediation and are known to influence native fish abundance, distribution, and survival. In addition to compiling, and documenting the compilation of, existing data, potential data analysis approaches that could be employed using the compiled data to quantitatively identify relations between chemical and physical conditions, and fish abundance and distribution in the Virgin River – a necessary step prior to quantifying the impacts of remediation scenarios on native fish – are discussed. Although this compilation does not include all discharge, water quality, or fish data previously collected for the Virgin River, it does provide an organized baseline set of data.

# Data Compilation

## Discharge

Discharge data were acquired from 21 sites on the Virgin River. Complete discharge records are presented in appendix 1, and the period of record for which data are available at these sites is summarized in table 1. Standard USGS methods were used to produce the discharge records (Rantz, 1982), and daily mean stream discharge data for each site were acquired from the USGS National Water Information System (NWIS) database (*http://water.data.usgs.gov/nwis*, accessed December, 2012). These 21 streamflow gaging stations are the only sites the USGS has operated, or currently operates on the Virgin River that provide a continuous record of discharge. Thirteen of the 21 sites currently (2012) have active streamflow gages. Point measurements of discharge not associated with a gaging station are not reported here. The average discharge record length is 30 years and varies from 273 days at the Virgin River Below Ash Creek Near LaVerkin, UT gage to 104 years at the Virgin River at Virgin, UT gage (table 1). Average daily mean discharge ranges from 5 $ft^3/s$ at the North Fork Virgin River Near Glendale, UT gage to 342 $ft^3/s$ at the Virgin River Above Halfway Wash Near Riverside, NV gage.

**Table 1.** Data availability summary and statistics for sites with continuously measured discharge along the Virgin River in Utah, Nevada, and Arizona.

[USGS, U.S. Geological Survey; STAID, station ID; $ft^3/s$, cubic feet per second]

| USGS National Water Information System station name | USGS STAID | Period of record | Average discharge ($ft^3/s$) | Standard deviation of discharge ($ft^3/s$) | Minimum discharge ($ft^3/s$) | Maximum discharge ($ft^3/s$) |
|---|---|---|---|---|---|---|
| East Fork Virgin River Near Glendale, UT | 9404450 | 1996-2012 | 18 | 20 | 3 | 624 |
| East Fork Virgin River Near Mount Carmel Junction, UT | 9404700 | 1992-2002 | 17 | 20 | 0 | 189 |
| East Fork Virgin River Near Springdale, UT | 9404900 | 1991-2012 | 57 | 50 | 26 | 2,120 |
| North Fork Virgin River Near Glendale, UT | 9405400 | 1972-2012 | 5 | 5 | 0 | 39 |
| North Fork Virgin River Below Bulloch Canyon Near Glendale, UT | 9405420 | 1974-1984 | 20 | 19 | 3 | 200 |
| North Fork Virgin River Above Zion Narrows Near Glendale, UT | 9405450 | 1978-1984 | 26 | 24 | 2 | 200 |
| North Fork Virgin River Above Big Bend Near Springdale, UT | 9405490 | 1991-1994 | 116 | 190 | 0 | 1,380 |
| North Fork Virgin River Near Springdale, UT | 9405500 | 1923-2012 | 104 | 158 | 22 | 4,990 |
| North Fork Virgin River Near Springdale, UT | 9405501 | 1968-1991 | 105 | 172 | 17 | 3,000 |
| Virgin River at Virgin, UT | 9406000 | 1909-2012 | 199 | 280 | 22 | 10,600 |
| Virgin River Above La Verkin Creek Near La Verkin, UT | 9406100 | 2005-2012 | 109 | 246 | 16 | 7,900 |
| Virgin River Below Ash Creek Near La Verkin, UT | 9407810 | 2004-2005 | 305 | 1,596 | 18 | 18,000 |
| Virgin River Above Quail Creek Near Hurricane, UT | 9408135 | 1989-2012 | 201 | 497 | 20 | 13,500 |
| Virgin River Near Hurricane, UT | 9408150 | 1967-2012 | 213 | 383 | 22 | 13,700 |
| Virgin River Near Bloomington, UT | 9413200 | 1977-2012 | 221 | 460 | 5 | 17,800 |
| Virgin River Near St. George, UT | 9413500 | 1950-2012 | 190 | 438 | 0 | 18,000 |
| Virgin River Above the Narrows Near Littlefield, AZ | 9413700 | 1998-2012 | 161 | 534 | 0 | 19,500 |
| Virgin River at Littlefield, AZ | 9415000 | 1929-2012 | 242 | 495 | 40 | 25,000 |
| Virgin River at Riverside, NV | 9415190 | 1970-1995 | 277 | 537 | 0 | 7,400 |
| Virgin River Above Halfway Wash Near Riverside, NV | 9415230 | 1977-1985 | 342 | 476 | 0 | 7,580 |
| Virgin River Above Lake Mead Near Overton, NV | 9415250 | 2006-2012 | 159 | 362 | 0 | 13,900 |

## Water Quality

Water-quality data were acquired from 87 sites on the Virgin River upstream of Lake Mead. Complete water-quality data sets are presented in appendix 2, and the period of record and number of samples collected at each site are summarized in table 2. Water-quality data compiled here are limited to constituents that are expected to change in response to remediation of Pah Tempe Springs and that are known to influence native fish abundance, distribution, and survival. These constituents include stream temperature, dissolved-oxygen concentration, and dissolved-solids concentration. Water-quality data were generated from samples collected by the following six agencies: the Arizona Department of Environmental Quality (AZDEQ), the Utah Department of Environmental Quality (UTDEQ), USU, the U.S. Environmental Protection Agency (EPA), the National Park Service (NPS), and the USGS. Discrete water-quality data generated from samples collected by the USGS were acquired from the NWIS database (accessed December 2012 at http://nwis.waterdata.usgs.gov/nwis), and data generated from samples collected by the AZDEQ, UTDEQ, EPA, and the NPS were acquired from the Water Quality Portal (WQP, http://www.waterqualitydata.us/, accessed December 2012). Water samples collected by the USGS were collected using standard USGS methods (U.S. Geological Survey, variously dated), and were analyzed at the USGS National Water Quality Laboratory (NWQL), in Denver, Colorado. Water samples collected by non-USGS entities were collected and analyzed according to organization-specific protocols. The average water-quality record length is 9.5 years, and varies from 1 day at a number of sites to 63 years at the Virgin River at Littlefield, AZ site (table 2). Forty eight of the 87 sites have fewer than 10 data points for each water-quality constituent, and only 5 sites have more than 100 data points for each water-quality constituent. The site with the most water-quality data is the same site that has the longest water-quality period of record, the Virgin River at Littlefield, AZ.

Of the 54 water-quality sites sampled by the USGS, continuous measurements of stream temperature, dissolved oxygen, and specific conductance (a proxy for dissolved-solids concentration) are available for 7 sites. Complete continuous water-quality data sets are presented in appendix 3, and the period of record for which data are available at these sites is summarized in table 3. Two of these sites, the Virgin River at Virgin, UT, and the Virgin River Above La Verkin Creek Near La Verkin, UT, have continuous data collected at 15-minute intervals through present (2014) day (table 3, fig. 1). Data for the other five sites are reported at a daily time step, and only historical data are available for these sites.

In addition to the continuous USGS water-quality data, the UTDNR and USU have collected continuous instream temperature data. Continuous temperature data were collected by the UTDNR at 17 sites on the mainstem of the Virgin River for different periods of record at each site (appendix 4, table 4). Data collected from 2001 to 2005 were collected at 15-minute, 30-minute or 1-hour intervals, whereas data collected after 2005 were collected at 10-minute intervals. Continuous temperature data were collected by USU at 5-minute intervals at four sites on the mainstem of the Virgin River for multiple days during five distinct time periods (appendix 5, table 4).

**Table 2.** Data availability summary for sites with water-quality data along the Virgin River in Utah, Nevada, and Arizona.

[USGS, U.S. Geological Survey; NWIS, National Water Information System; STAID, station ID; DO, dissolved oxygen; TDS, total dissolved solids; ROE, residue on evaporation at 180 degrees Celsius; SC, sum of constituents; WQP, Water Quality Portal]

| NWIS Data | | | | | | |
|---|---|---|---|---|---|---|
| USGS NWIS station name | USGS STAID | Period of record | Number of temperature data points | Number of DO data points | Number of TDS (ROE) data points | Number of TDS (SC) data points |
| East Fork Virgin River Near Glendale, UT | 9404450 | 1966-2012 | 196 | 4 | 1 | 119 |
| East Fork Virgin River Near Springdale, UT | 9404900 | 2008-2012 | 28 | 0 | 0 | 18 |
| Nf Virgin River Near Glendale, UT | 9405400 | 1973-1978 | 38 | 0 | 0 | 37 |
| N Fk Virgin R Blw Bulloch Canyon Nr Glendale | 9405420 | 1974-1986 | 69 | 2 | 0 | 64 |
| N Fk Virgin R Abv Zion Narrows Nr Glendale | 9405450 | 1979-1986 | 54 | 4 | 3 | 24 |
| North Fork Virgin River Near Springdale, UT | 9405500 | 1983-2012 | 55 | 0 | 0 | 6 |
| North Fork Virgin River Nr Springdale, UT | 9405501 | 1973-1991 | 63 | 2 | 0 | 2 |
| Virgin River At Virgin, UT | 9406000 | 1962-2012 | 328 | 77 | 9 | 125 |
| Virgin River Ab La Verkin Creek Nr La Verkin, UT | 9406100 | 2009-2012 | 83 | 78 | 5 | 76 |
| Virgin River Ab Quail Creek Near Hurricane, UT | 9408135 | 1989-2012 | 46 | 0 | 6 | 44 |
| Virgin River Near Hurricane, UT | 9408150 | 1967-2012 | 294 | 4 | 7 | 204 |
| Virgin River Near Bloomington, UT | 9413200 | 1977-2012 | 147 | 4 | 4 | 18 |
| Virgin R At Bloomington, UT | 9413300 | 1978-1979 | 16 | 13 | 16 | 0 |
| Virgin River Near St. George, UT | 9413500 | 1966-2013 | 59 | 9 | 14 | 0 |
| Virgin R. Abv I15 Rest Area Nr Littlefield, AZ | 9413600 | 1977-1979 | 18 | 17 | 18 | 0 |
| Virgin R. Blw I15 Rest Area Nr Littlefield, AZ | 9413650 | 1977-2010 | 19 | 19 | 18 | 0 |
| Virgin Rv Abv The Narrows Nr Littlefield, AZ | 9413700 | 1998-2011 | 68 | 59 | 0 | 0 |
| Virgin R At Mouth Of Narrows Nr Littlefield, AZ | 9413800 | 1977-1979 | 26 | 23 | 26 | 2 |
| Virgin Rv At Littlefield, AZ | 9415000 | 1949-2012 | 563 | 255 | 680 | 31 |
| Virgin Rv At Mesquite, NV | 9415090 | 1992-1992 | 2 | 2 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Virgin Rv At Riverside, NV | 9415190 | 1974-1995 | 23 | 2 | 0 | 2 |
| Virgin Rv Blw Riverside, NV | 9415200 | 1969-1974 | 28 | 23 | 24 | 15 |
| Virgin Rv Abv Halfway Wash Nr Riverside, NV | 9415230 | 1978-1995 | 94 | 59 | 61 | 56 |
| Virgin Rv Abv Lake Mead Nr Overton, NV | 9415250 | 2008-2012 | 11 | 6 | 8 | 0 |
| Virgin River Abv Beaver Dam Wash, AZ | 365006113585301 | 1981-1982 | 4 | 4 | 0 | 3 |
| Virgin River At Desert Springs | 365440113534001 | 2012 | 0 | 0 | 1 | 1 |
| Virgin River Blw Virgin River Gorge Springs, AZ | 365508113513301 | 1981-1982 | 2 | 2 | 0 | 2 |
| (B-41-14)21cba Virgin R. Blw Sullivan Canyon | 365614113492701 | 2010 | 1 | 0 | 0 | 1 |
| (B-41-14)21ada Virgin R. Abv Sullivan Canyon | 365625113484801 | 2010 | 1 | 0 | 0 | 1 |
| (B-41-14)14ccc Virgin R. At I-15 Rest Area | 365648113472401 | 2010 | 1 | 0 | 0 | 0 |
| Virgin River At Black Rock Gulch, Nr St. George, UT | 365812113434101 | 2009-2010 | 2 | 0 | 2 | 1 |
| Virgin River Below Confluence, UT | 370842113020601 | 1981-1982 | 4 | 4 | 0 | 3 |
| East Fork Virgin River Above Confluence, UT | 370947113003801 | 1981-1982 | 4 | 4 | 0 | 4 |
| North Fork Virgin River Above Confluence, UT | 370948113004401 | 1981-1982 | 4 | 4 | 0 | 2 |
| Virgin River Above Leeds Creek, UT | 371042113223501 | 1981-1982 | 5 | 5 | 0 | 3 |
| Virgin River Lower Sect | 371100113211501 | 1975 | 1 | 0 | 0 | 0 |
| Virgin River Below La Verkin Hot Springs, UT | 371122113162201 | 1981-2010 | 11 | 4 | 7 | 0 |
| Virgin River Above La Verkin Hot Springs, UT | 371127113155901 | 1981-2010 | 10 | 4 | 6 | 0 |
| Virgin River Upper Sect | 371155113180501 | 1975 | 1 | 0 | 0 | 0 |
| Virgin River Above North Creek, UT | 371204113103501 | 1981-1982 | 4 | 4 | 0 | 0 |
| Virgin River Below Ash Creek, UT | 371208113172501 | 1981-1982 | 5 | 5 | 0 | 0 |
| Nf Virgin River Nr Springdale Qw | 371235112584002 | 1973-1980 | 23 | 0 | 0 | 0 |
| E. Fk. Virgin R. At Mt. Carmel Junction, UT | 371247112410801 | 1981-1982 | 4 | 4 | 0 | 0 |
| North Fork Virgin River At Mouth Of Narrows, UT | 371705112565001 | 1981-1987 | 6 | 4 | 0 | 0 |
| North Fork Virgin River At Big Spring | 371952112572101 | 1986 | 1 | 0 | 0 | 0 |
| East Fk Virgin River Abv Lydias Canyon, UT | 372028112361201 | 1982 | 1 | 1 | 0 | 0 |
| N Fk Virgin River At Confluence With Deep Creek | 372134112570301 | 1986 | 1 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| N. F. Virgin River Past | 372218112521001 | 1987 | 1 | 0 | 1 | 0 |
| North Fork Virgin River Above Deep Creek | 372218112523301 | 1986 | 1 | 0 | 0 | 0 |
| E. Fk. Virgin R. Above Stout Canyon, UT | 372237112352501 | 1981-1982 | 2 | 2 | 0 | 0 |
| No. Fork Virgin River Near Pond | 372247112504601 | 1987 | 0 | 0 | 1 | 0 |
| N Fk Virgin R Nr Willow Canyon | 372405112483301 | 1986 | 2 | 0 | 0 | 0 |
| E. Fk. Virgin R. At Highway 136 Bridge, UT | 372538112320701 | 1981-1982 | 4 | 4 | 0 | 0 |
| N Fk Virgin R Blw Rosy Canyon | 372642112470401 | 1986 | 3 | 0 | 1 | 0 |

**WQP Data**

| Monitoring location name | Monitoring location identifier | Period of record | Number of temperature data points | Number of DO data points | Number of TDS data points |
|---|---|---|---|---|---|
| N Fork Virgin R Above Confluence With E Fork | 11NPSWRD-ZION_EPA_NFVR1 | 1976 | 3 | 3 | 0 |
| E Fork Virgin R Above Confluence With N Fork | 11NPSWRD-ZION_EPA_VR5 | 1976 | 2 | 2 | 0 |
| Virgin River Near Virgin UT | 11NPSWRD-ZION_EPA_VR7 | 1976 | 2 | 2 | 0 |
| Virgin River Near La Verkin Hot Springs | 11NPSWRD-ZION_EPA_VR8 | 1976 | 3 | 3 | 0 |
| Virgin River | 11NPSWRD-ZION_NF_VR | 1987 | 1 | 0 | 0 |
| East Fork Virgin River Below Parunuweap Canyon | 11NPSWRD-ZION_NPSWRD_157 | 1992 | 11 | 9 | 0 |
| Virgin River At Virgin UT | 11NPSWRD-ZION_UTDNR_32 | 1981-1982 | 5 | 5 | 0 |
| Virgin River Above North Creek | 11NPSWRD-ZION_UTDNR_33.1 | 1981-1982 | 5 | 5 | 0 |
| Virgin River Below Confluence | 11NPSWRD-ZION_UTDNR_38 | 1981-1982 | 5 | 5 | 0 |
| North Fork Of The Virgin River Above Confluence | 11NPSWRD-ZION_UTDNR_39 | 1981-1982 | 5 | 5 | 0 |
| North Fork Of The Virgin River Near Springdale | 11NPSWRD-ZION_UTDNR_40 | 1981-1982 | 4 | 4 | 0 |
| East Fork Virgin River Above Confluence | 11NPSWRD-ZION_UTDNR_56 | 1981-1982 | 5 | 5 | 0 |
| Virgin River - At Littlefield, AZ | 21ARIZ_WQX-CGVGR039.41 | 2009-2010 | 4 | 2 | 10 |
| Virgin River - Below The Narrows | 21ARIZ_WQX-CGVGR043.36 | 2010 | 1 | 1 | 3 |
| Virgin River - At I-15 Rest Stop | 21ARIZ_WQX-CGVGR052.23 | 2009-2010 | 4 | 2 | 10 |
| Virgin River | NARS-WAZP99-0712 | 2002 | 1 | 1 | 0 |
| Virgin R At Utah-Ariz Stateline | UTAHDWQ_WQX-4950010 | 1976-1983 | 5 | 4 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| Virgin R Bl First Narrows & New St George WWTP | UTAHDWQ_WQX-4950020 | 1984-2209 | 147 | 149 | 155 |
| Virgin R At Bloomington Xing Ab St George WWTP | UTAHDWQ_WQX-4950120 | 1977-2009 | 73 | 73 | 28 |
| Virgin R Ab Santa Clara R & Bl Old St George WWTP | UTAHDWQ_WQX-4950130 | 1976-1999 | 20 | 11 | 14 |
| Virgin River At I-15 Virgin R Gorge Rest Area (AZ) | UTAHDWQ_WQX-4950160 | 1991 | 2 | 2 | 2 |
| Virgin R Se Of St George @ Cr Xing | UTAHDWQ_WQX-4950200 | 1975-2006 | 96 | 75 | 75 |
| Virgin R Ab Washington Lagoons | UTAHDWQ_WQX-4950260 | 1982-1983 | 6 | 4 | 0 |
| Virgin R Bl Hot Springs | UTAHDWQ_WQX-4950300 | 2000-2002 | 2 | 2 | 0 |
| Virgin R At U15 Xing W Of Hurricane | UTAHDWQ_WQX-4950320 | 1976-2006 | 134 | 126 | 126 |
| Virgin R At U17 Xing N Of Hurricane (E Of Laverkin) | UTAHDWQ_WQX-4950810 | 1980-1985 | 11 | 11 | 8 |
| Virgin R 1 Mi E Of Virgin | UTAHDWQ_WQX-4950850 | 1982-2006 | 89 | 84 | 90 |
| Virgin R At Cr Xing In Rockville | UTAHDWQ_WQX-4950900 | 1976-1982 | 14 | 14 | 12 |
| N Fk Virgin R Ab Cnfl / E Fk Virgin R | UTAHDWQ_WQX-4950950 | 1979-2006 | 167 | 164 | 165 |
| N Fk Virgin R Bl Zion Natl Park WWTP Outfall | UTAHDWQ_WQX-4951100 | 1976-1984 | 5 | 1 | 1 |
| N Fk Virgin R Ab Zion Natl Park WWTP Outfall | UTAHDWQ_WQX-4951130 | 1975-1976 | 5 | 0 | 5 |
| N Fk Virgin R @ Hwy 9 Xing In Zion NP | UTAHDWQ_WQX-4951195 | 2006 | 3 | 3 | 3 |
| E Fk Virgin R Ab Cnfl / N Fk Virgin R | UTAHDWQ_WQX-4951400 | 1982-2009 | 157 | 155 | 157 |

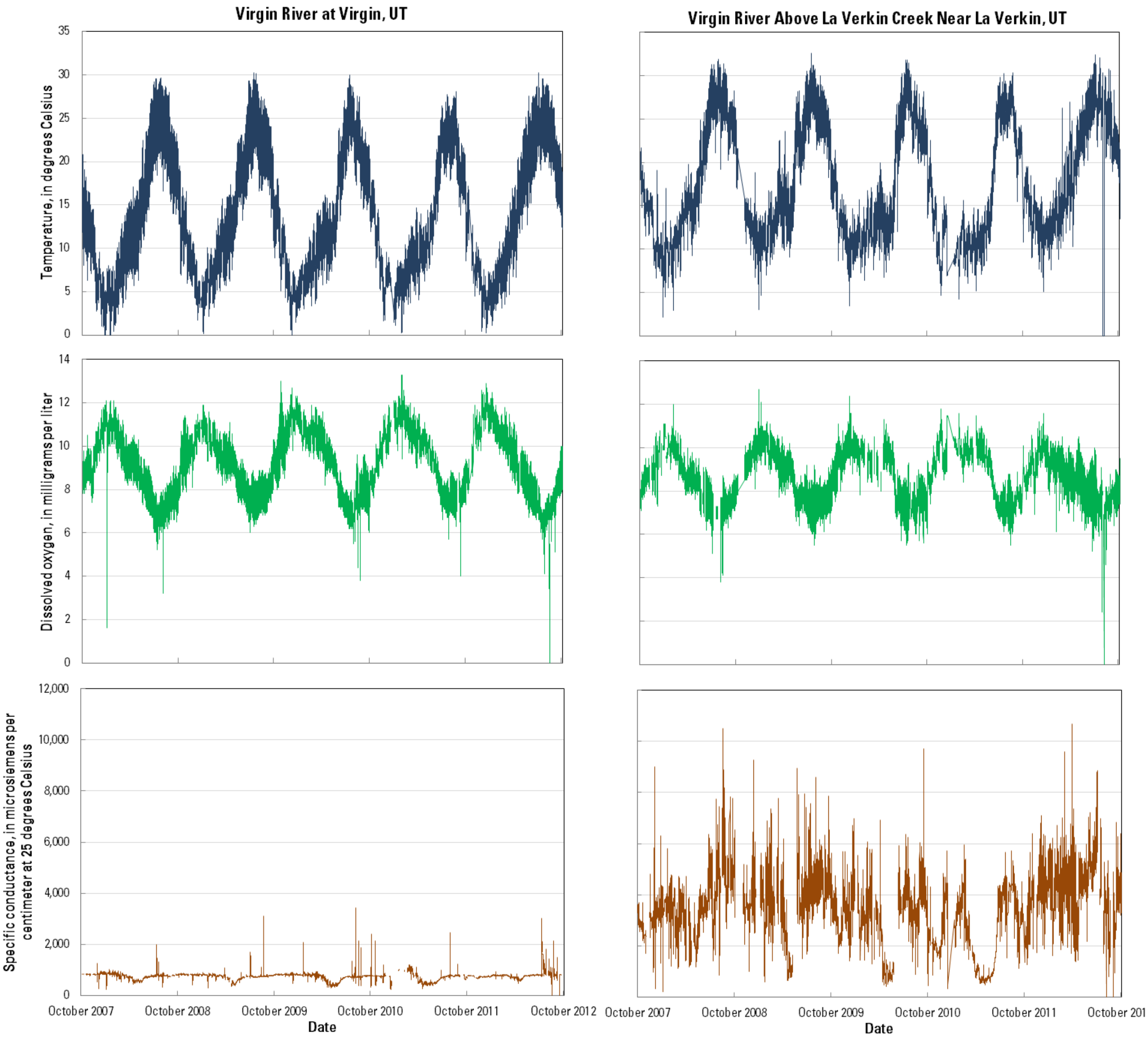


**Figure 1.** Time series plots of stream temperature, dissolved oxygen, and specific conductance measured at 15-minute intervals from 2007-2012 at the Virgin River at Virgin, UT, and Virgin River Above La Verkin Creek Near La Verkin, UT, streamgaging stations. The Virgin River at Virgin, UT, gage is located directly upstream of where Pah Tempe Springs discharge to the Virgin River, and the Virgin River Above La Verkin Creek Near La Verkin, UT, gage is located directly downstream of the Pah Tempe Springs confluence.

**Table 3.** Data availability summary for U.S. Geological Survey sites with continuous water-quality data along the Virgin River in Utah, Nevada, and Arizona.

[USGS, U.S. Geological Survey; STAID, station ID; ND, no data]

| Station name | USGS STAID | Stream temperature | Dissolved oxygen | Specific conductance | Reporting interval |
|---|---|---|---|---|---|
| Virgin River at Virgin, UT | 9406000 | 2007-2012 | 2007-2012 | 2007-2012 | 15 minutes |
| Virgin River Above La Verkin Creek Near La Verkin, UT | 9406100 | 2007-2012 | 2007-2012 | 2007-2012 | 15 minutes |
| Virgin River Below Ash Creek Near La Verkin, UT | 9407810 | 2004-2005 | 2004-2008 | 2004-2008 | Daily |
| Virgin River Above Quail Creek Near Hurricane, UT | 9408135 | 1992-1993 | ND | ND | Daily |
| Virgin River Near Hurricane, UT | 9408150 | 1967-1993 | ND | ND | Daily |
| Virgin River at Littlefield, AZ | 9415000 | 1947-1988 | ND | 1949-1988 | Daily |
| Virgin River Above Lake Mead Near Overton, NV | 9415250 | 2008-2010 | 2009-2010 | 2008-2010 | Daily |

**Table 4.** Data availability summary for Utah Department of Natural Resources (UTDNR) and Utah State University (USU) sites with continuous temperature data.

| UTDNR Data | | | |
|---|---|---|---|
| **Station Name** | **Latitude** | **Longitude** | **Period of record** |
| Sheep Bridge | 37.199523 | -113.212385 | 2001-2012 |
| Above Quail Creek Diversion | 37.199512 | -113.234083 | 2004-2012 |
| Below Quail Creek Diversion | 37.196936 | -113.240181 | 2004-2012 |
| Below Pah Tempe | 37.190546 | -113.276625 | 2001-2012 |
| Below LaVerkin Hydroplant | 37.190904 | -113.279553 | 2004-2012 |
| Above LaVerkin Creek | 37.197309 | -113.285289 | 2001-2012 |
| Below Ash Creek | 37.200954 | -113.291122 | 2001-2012 |
| Above Gould's Wash | 37.194834 | -113.333193 | 2004-2012 |
| Above Quail Creek Near Stratton Pond | 37.180386 | -113.372732 | 2001-2012 |
| At Hurricane Bridge (SR9) | 37.162705 | -113.395094 | 2001-2012 |
| Above Washington Fields Diversion | 37.128624 | -113.422450 | 2001-2012 |
| Below Washington Fields Diversion | 37.117062 | -113.439985 | 2010-2012 |
| Below Palmer Ranch | 37.117848 | -113.465117 | 2005-2012 |
| Twin Bridges Population Response Station | 37.087092 | -113.550253 | 2010 |
| Bloomington USGS Gage | 37.070779 | -113.581544 | 2005-2012 |
| Man O' War Population Response Station | 37.041641 | -113.601872 | 2010-2012 |
| Below Stateline Barrier | 37.014810 | -113.681295 | 2004-2012 |

| USU Data | | | |
|---|---|---|---|
| **Station Name** | **Latitude** | **Longitude** | **Periods of record** |
| Below Gould's Wash | 37.199994 | -113.342328 | 7/19/2005-7/21/2005<br>9/28/2005-10/1/2005<br>2/6/2007-2/9/2007<br>5/6/2007-5/16/2007<br>6/20/2007-7/2/2007 |
| Above Stratton Pond | 37.181653 | -113.373039 | 5/6/2007-5/16/2007<br>6/21/2007-6/25/2007 |
| Hurricane Bridge | 37.161686 | -113.396717 | 7/18/2005-7/21/2005<br>9/28/2005-10/1/2005<br>2/6/2007-2/9/2007<br>5/6/2007-5/16/2007<br>6/21/2007-6/25/2007 |
| Above Washington Fields Diversion | 37.119289 | -113.430272 | 7/19/2005-7/21/2005<br>9/28/2005-10/1/2005<br>2/6/2007-2/9/2007<br>5/6/2007-5/16/2007<br>6/20/2007-6/28/2007 |

## Native Fish Abundance

Native fish abundance data were acquired from the Virgin River fishes database and from data sets generated by the UTDNR. The Virgin River fishes database contains long-term monitoring data on native fish in the Virgin River and major tributaries, and is included as appendix 6. The database contains data collected in the mainstem of the Virgin River from 1976 to 2005. The database has built-in “forms” that allow the user to run queries for selected conditions. The “Report Form-Master” data form allows the user to select fish abundance data by site and date range. Using the “Station Name Lookup” pull-down menu, the user can select a site. Following site selection, the “ID Lookup” field will be populated with the Site ID. The Site ID indicates the water body and location, in upstream river miles. For example, the “Above LaVerkin Creek” site has a corresponding Site ID of “VR095.96”, which indicates that the site is on the Virgin River 95.96 miles upstream from Lake Mead. Once the user has identified the site(s) from which they would like to acquire data, a spatial range using the “Downstream site” and “Upstream site” data fields can be defined. A temporal range also can be defined using the “Begin” and “End” Date/Hour/Min data fields. A variety of data output formats are available, including data by individual seining units, data combining seining units by date, and data combined by species, station, or station/date.

Fish density data from the Virgin River Gage (site ID: VR104.72) and Virgin River Above Quail Creek (site ID: VR089.18) sites are shown in figure 2 as examples of the types of data available in the database. These sites roughly correspond to the Virgin River at Virgin, UT (USGS STAID: 9406000) and the Virgin River Above Quail Creek Near Hurricane, UT (USGS STAID: 9408135) gaging stations respectively, which have been sampled for water quality by the USGS (tables 1, 2, and 3).

The UTDNR has a number of ongoing fish monitoring efforts. Data sets from two of those efforts (full pass and population response stations) are included here. The full pass sampling is a more intensive sampling effort that occurs less regularly, as compared with the population response stations sampling, which is a less intensive sampling effort that occurs on a regular basis. The full pass data set contains information on native and non-native fish abundance in six reaches of the mainstem of the Virgin River from below Pah Tempe Springs to the Washington Fields Diversion (appendix 7). The full pass data set was generated by systematically seining all available habitats within each of the six reaches (see appendix 7 for reach definitions) two to three times per year from 2002 to 2012. Fish were enumerated into two age/size classes (young of year and adult), with the exception of fish sampled during the first two samplings of 2002. The methodology and results from each year of full pass sampling are detailed in yearly reports generated by the UTDNR (e.g. for 2004 sampling see Fridell and Morvilius, 2005; similar reports are available for all other sample years). The UTDNR population response stations data set contains information on native fish abundance in seven 1.5-mi reaches of the mainstem of the Virgin River (appendix 8). The Quail Creek station was split into two 0.75-mi reaches (Above Quail Creek and Below Quail Creek). Fifty seine hauls were conducted monthly from March-October and twice in the winter months from 2003 to 2012 in each reach in proportion to available habitat in the reach. Fish were measured, separated into two size classes (young of year and adult) and enumerated. The methodology and results from each year of population response station sampling are detailed in yearly reports generated by the UTDNR (e.g. for 2005 sampling see Bennion and Fridell, 2006; similar reports are available for all other sample years).

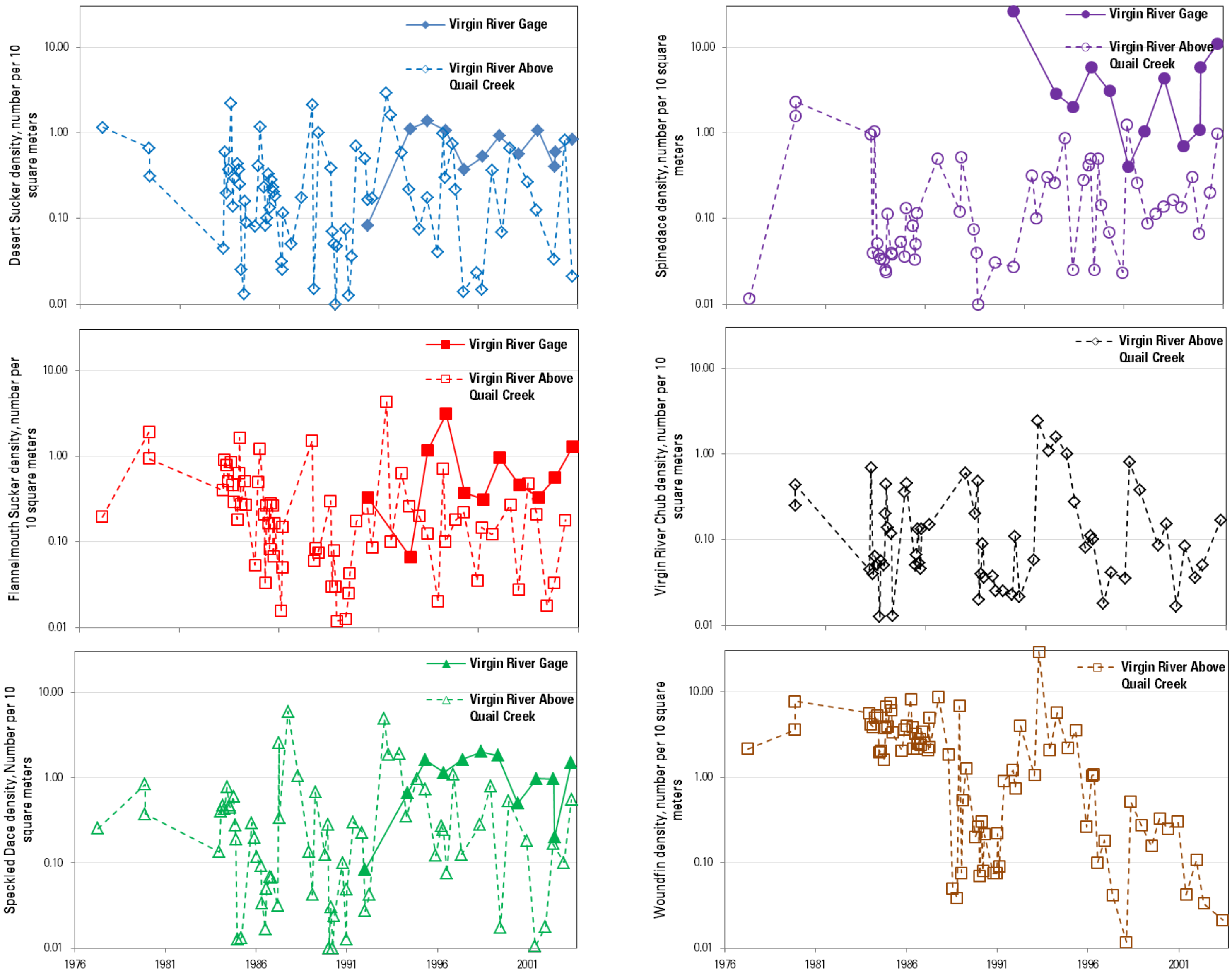


**Figure 2.** Native fish density data from the Virgin River Gage (VR104.72) and Virgin River Above Quail Creek (VR089.18) sites. Neither Virgin River chub nor woundfin were found during sampling at the Virgin River Gage site. The Virgin River Gage site is located upstream of where Pah Tempe Springs discharge to the Virgin River, and the Virgin River Above Quail Creek site is located downstream of the Pah Tempe Springs confluence.

## Possible applications of data and next steps

There are two requirements that need to be met to answer the overarching question, “How will various remediation scenarios to reduce the load of dissolved solids from Pah Tempe Springs into the Virgin River influence the abundance, distribution, and survival of native fish?” The first of these requirements is a foundational understanding of the relations between discharge, water quality, and fish abundance. The second is that adequate data are available to model the effects of abiotic drivers on native fish abundance, distribution, and survival. We discuss an approach by which the data compiled here could be used to directly address the first requirement, that is, developing a quantitative understanding of the relations between abiotic physical and chemical conditions, and native fish abundance and distribution in the Virgin River. Such an understanding will provide insight into the adequacy of available data for model development. Final determination of the adequacy of the data compiled here for the purpose of modeling the effects of abiotic drivers on native fish (the second requirement) is beyond the scope of this report, and will be dependent upon the constituents being modeled and the specific modeling approaches that are used.

Data sources required to meet the first requirement would include all of the discharge, water quality, and fish data compiled in this report. Measured discharge and water-quality conditions as well as statistics (i.e. average, standard deviation, minimum, maximum, concentration/discharge) could be assessed as drivers of change in fish community composition. A non-metric multidimensional (NMDS) ordination plot could be generated to identify spatial and temporal patterns in fish community composition. Subsequently, correlations between the fish community and all possible subsets of discharge and water-quality conditions/statistics could be assessed by using BIOENV (Clarke and Ainsworth, 1993). The use of NMDS and BIOENV to quantify relations between aquatic biota and abiotic environmental conditions has been applied successfully in other southwestern streams and rivers (Miller and Brasher, 2011). This proposed approach would identify drivers (i.e. discharge, temperature, dissolved solids, and dissolved oxygen) of change in fish abundance across space and time, and build upon analyses investigating changes in fish abundance in response to changes in discharge and temperature using some of the population response station fish data collected by UTDNR staff (Meribeth Huizinga, oral commun., 2013). This approach would also identify potential data gaps that could inform future sampling/monitoring efforts to, in part, provide data needed for modeling abiotic-biotic relations. Coupling abiotic-biotic relations identified in this way with future predictions of how water quality and discharge may change in response to various Pah Tempe Springs remediation scenarios would provide the foundational information needed to develop assessment methods and models capable of predicting the abundance, distribution, and survival of native fish in response to remediation efforts.

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