A Review of Suspended and Bedded Sediments (SABS) and Associated Water Quality Standards for the Carson River

A supporting document for the Carson River Report Card

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Sediment in Carson River below Mexican Dam following gully erosion event in the Pine Nut Hills

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Introduction

In support of its Clean Water Act responsibilities, the Nevada Division of Environmental Protection (NDEP) – Bureau of Water Quality Planning (BWQP) is developing a Carson River Watershed Assessment or Report Card. Drawing upon numerous studies and monitoring efforts, the Report Card will provide a compilation of current knowledge about the chemical, physical and biological health of the Carson River watershed with a focus on aquatic life uses from the Nevada/California stateline to Lahontan Reservoir. It is hoped that the Report Card will be a valuable tool for educating the public, agencies and decisionmakers on the state of the river (from a Clean Water Act perspective), thereby providing direction for their future actions and decisions. The Report Card will also be a key planning tool for BWQP in possible future steps, such as standards revisions, comprehensive Total Maximum Daily Loads (TMDLs), watershed plan development and restoration projects.

The purpose of this report is to summarize suspended and bedded sediment (SABS) conditions in the Carson River system (Figure 1), and review the existing associated water quality standards set to control related problems. Also, recommendations on additional work and water quality standard revisions are provided.

Background

SABS and Impairment

Rather than limiting the discussion to only total suspended solids and turbidity, this report takes a broader look at SABS in the Carson system. As used by EPA (2006), SABS are defined as:

> *Organic and inorganic particles that are suspended in, are carried by, or accumulate in waterbodies. This definition includes the frequently used terms clean sediment, suspended sediment, total suspended solids, turbidity, bedload, fines, deposits, or, in common terms, soils or eroded materials.*

Certain SABS levels are natural and should be expected in streams. However beneficial uses can be affected when SABS are out of balance (EPA, 2006). Problems due to SABs have been identified as one of the major causes of water quality impairment in the U.S. (EPA, 2003). Aquatic life uses have been identified as one of the most sensitive uses affected by SABS that are out of balance with more natural conditions. Impacts can generally be divided into 2 categories: suspended and bedded sediments.

<u>Suspended Sediments</u>

SABS can impact aquatic life uses in a number of different ways. Suspended material along with the associated turbidity affects the light available for photosynthesizing plants and can limit periphyton growth. Reduced periphyton growth can impact macroinvertebrates and other species higher on the food chain. Many macroinvertebrates are grazers and rely on periphyton for food (Waters, 1995; Newcombe and MacDonald, 1991). Suspended material also affects the visual capability of aquatic animals (Waters, 1995). With reduced visual ability follows reduced feeding and growth rates. Also, high suspended levels can cause physical abrasion and clogging of filtration and respiratory organs.

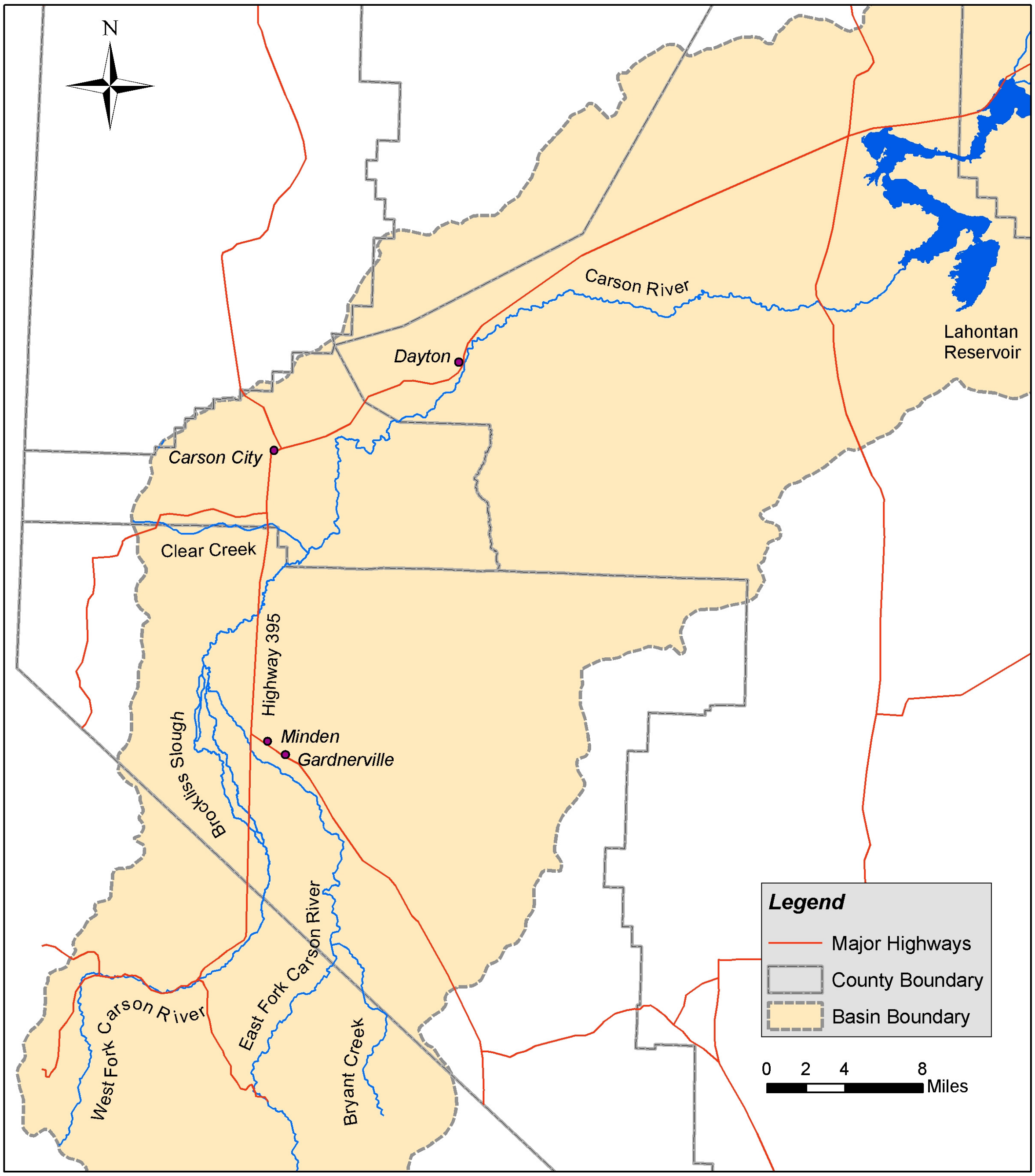


Figure 1. Carson River Study Area

Bedded Sediments

Streambed sedimentation impacts the aquatic life in a variety of ways by reducing: 1) the habitat available for macroinvertebrates, 2) the quality of gravels for fish spawning; and 3) amount of habitat for fish rearing (Waters, 1995). Many species of fish and macroinvertebrates rely on the interstitial spaces in the stream substrates to lay their eggs. Even small levels (a few millimeters) of sediment deposition can increase egg mortality (EPA, 2006).

Existing Water Quality Standards

Nevada's water quality standards for the East and West Forks, and the Carson River are contained in Nevada Administrative Code (NAC) 445A.146 through 445A.158. The total suspended solids (TSS) and turbidity numeric criteria are provided in Table 1. Two different types of numeric criteria exist: 1) Requirements to Maintain Existing Higher Quality (RMHQ), and 2) beneficial use standards (BUS). RMHQs are based upon existing quality (typically set at the 95th percentile of the available data) and have been set as part of Nevada's antidegradation approach for its waters. By definition, RMHQs are more restrictive than BUSs. BUSs are set at levels needed to protect the beneficial uses. Typically, BUS values are based upon either EPA recommendation, site specific criteria, or other information.

Nevada's 303(d) List

Every two years, Nevada is required under the federal Clean Water Act to produce a list (303(d) List) of waters not meeting applicable water quality standards (BUSs only). Since 1992, various reaches have been on the 303(d) list for exceedances of the TSS and/or turbidity standards. Table 2 summarizes the Carson reaches on the 2006 303(d) List for TSS and turbidity. It is important to recognize that the 303(d) List is rather dynamic with reaches coming on the list one cycle only to be removed during the next cycle, and then back on the next. A number of reasons have led to this dynamic nature: 1) TSS and turbidity conditions are highly variable depending in a large part upon flow levels; 2) the amount of monitoring data available for evaluation can vary; and 3) the methodology used in determining listings has changed over time.

Table 1. Summary of TSS and Turbidity Water Quality Standards in the Carson River above Lahontan Reservoir

<table>
<tr><th rowspan="2">NAC</th><th rowspan="2">Water body</th><th rowspan="2">Reach</th><th colspan="2">Total Suspended Solids (mg/l)</th><th colspan="2">Turbidity (NTU)</th></tr>
<tr><th>RMHQ</th><th>BUS</th><th>RMHQ</th><th>BUS</th></tr>
<tr><td>445A.147</td><td>West Fork Carson</td><td>Stateline</td><td>15 (AA)</td><td rowspan="3">25 (SV)</td><td>3 (AA)
5 (SV)</td><td rowspan="11">10 (SV)</td></tr>
<tr><td>445A.148</td><td>Bryant Creek</td><td>Stateline</td><td rowspan="12">None</td><td>None</td></tr>
<tr><td>445A.149</td><td rowspan="3">East Fork Carson</td><td>Stateline</td><td>5 (AA)
8 (SV)</td></tr>
<tr><td>445A.150</td><td>Stateline to Hwy 395</td><td rowspan="10">80 (SV)</td><td rowspan="10">None</td></tr>
<tr><td>445A.151</td><td>Hwy 395 to Muller Lane</td></tr>
<tr><td rowspan="3">445A.152</td><td>West Fork Carson</td><td>Stateline to confluence</td></tr>
<tr><td>East Fork Carson</td><td>Muller Lane to confluence</td></tr>
<tr><td>Carson River</td><td>Confluence to Genoa Lane</td></tr>
<tr><td>445A.153</td><td>Carson River</td><td>Genoa Lane to Cradlebaugh Bridge (Hwy 395)</td></tr>
<tr><td>445A.154</td><td>Carson River</td><td>Cradlebaugh (Hwy 395) Bridge to Mexican Ditch Gage</td></tr>
<tr><td>445A.155</td><td>Carson River</td><td>Mexican Ditch Gage to New Empire</td></tr>
<tr><td>445A.156</td><td>Carson River</td><td>New Empire to Dayton Bridge</td><td rowspan="2">50 (SV)</td></tr>
<tr><td>445A.157</td><td>Carson River</td><td>Dayton Bridge to Weeks (Hwy 95)</td></tr>
</table>

AA = Annual Average
SV = Single Value

Table 2. TSS and Turbidity Listings on 2006 303(d) List

NAC	Water body	Reach	Total Suspended Solids	Turbidity
445A.147	West Fork Carson	Stateline	X	
445A.148	Bryant Creek	Stateline	X	X
445A.149	East Fork Carson	Stateline	X	X
445A.150		Stateline to Hwy 395	X	X
445A.151		Hwy 395 to Muller Lane	X	X
445A.152	West Fork Carson	Stateline to confluence		X
	East Fork Carson	Muller Lane to confluence		
	Carson River	Confluence to Genoa Lane		
445A.153	Carson River	Genoa Lane to Cradlebaugh Bridge (Hwy 395)		X
445A.154	Carson River	Cradlebaugh (Hwy 395) Bridge to Mexican Ditch Gage		X
445A.155	Carson River	Mexican Ditch Gage to New Empire		X
445A.156	Carson River	New Empire to Dayton Bridge	X	
445A.157	Carson River	Dayton Bridge to Weeks (Hwy 95)		

Major Past Studies

Sediment Transport Model for the East Fork of the Carson River, Carson Valley, Nevada (Katzer and Bennett, 1980)

Using a sediment-transport simulation model, Katzer and Bennett predicted bedload and suspended-sediment transport and channel-bed scour and fill at various locations on the East Fork Carson River from the Allerman Canal Diversion to the confluence with the West Fork Carson River.

Key Findings/Conclusions:

- Above Muller Lane, the median diameter (D_{50}) of the stream bed material was found to range from 10 to 20 millimeters (medium to coarse gravel). Below Muller Lane, the D_{50} of the stream bed material dropped to about 0.5 millimeter (medium sand). These findings are comparable to those identified by Pahl (2006) as part of a relative bed stability investigation.

- Data collected during the 50-day sampling period (April 27 to June 15, 1978) indicated that about 60,000 tons of sediment were transported into the reach, while only 14,000 tons were transported out, with about 46,000 tons being deposited in the reach.

- Using the simulation model, Katzer and Bennett predicted an annual average sediment load inflow and outflow of 50,000 and 24,000 tons, respectively. The model predicted a net deposition of about 26,000 tons/year, with a majority of the deposition occurring between the Cottonwood Diversion Dam and Highway 88. This deposition area was the site of historic sand and gravel mining operations.

Fluvial Geomorphic Assessment of the Carson River with Implication for River Management (Inter-Fluve, Inc., 1997)

Inter-Fluve put together an extensive geomorphic assessment of the Carson River, with the overall intent of the project "…to compile information and recommendations that will act as a platform for intelligent land use decision making, active management, and a base level geomorphic study for future river analysis projects.

Key Findings/Conclusions:

- Inter-Fluve characterized the overall stability of the Carson River and its forks as poor, with "…miles and miles of eroding banks, a large potential and in-channel sediment supply, and a degraded riparian corridor." The main influences on the stability have been identified as historic activities, levee construction, channelization, diversions and ditches and livestock grazing.

- In some locations, permanent diversion structures serve as control on upstream headcutting. However, the push-up diversions are not believed to serve as beneficial grade controls, and may actually create more instability.

- Most surveyed section indicates an enlarged and/or incised channel. With higher flows contained within many of the reaches, flow energy is not dissipated on the floodplain but is concentrated within the stream channel, leading to increased stream erosion.

- The report presents general recommendations to enhance river health and reduce instability. Specific recommendations are provided on a reach by reach basis. Inter-Fluve concludes that "…efforts should be focused on aiding natural recovery process, reducing current impacts, managing for future river changes, and improving the condition of unstable reaches where possible."

Carson River Relative Bed Stability Investigation (Pahl, 2006)

Utilizing EPA's EMAP (Environmental Monitoring and Assessment Program) protocols, field data were collected and analyzed to characterize substrate/stability conditions for various site within the Carson River system (from stateline to Lahontan Reservoir).

Key Findings/Conclusions:

- Relative Bed Stability Indices suggest that the upper stream reaches (East Fork Carson River above Lutheran Bridge, West Fork Carson River above Brockliss Slough) are more stable than the lower sites; and that the sediment supply is not overwhelming the transport ability of the upper reaches.

- High levels of silt and sand (>80% of the substrate) were identified at: 1) Carson River above Highway 395; 2) Carson River above Mexican Gage; and 3) Carson River below Weeks Bridge (Highway 95A). The high levels of silt and sand leave little useable habitat for fish spawning and macroinvertebrates.

Carson River: Phase I – Total Maximum Daily Loads for Total Suspended Solids and Turbidity (NDEP, 2007)

Several segments of the Carson River have been included on the State's 303(d) List for exceedances of the TSS and turbidity standards. This TMDL document was produced to address these listings as required by federal regulations.

Key Finding/Conclusions:

- At most of the NDEP monitored sites, the highest occurrences of standards violations occur during the period April through June, with somewhat lesser violation frequencies for January through March.

- Regression relationships between turbidity and TSS were calculated at several NDEP monitoring sites. Since turbidity cannot be expressed as a load, TSS surrogate thresholds were developed for the purpose of developing turbidity TMDLs. TSS surrogates were found to be more restrictive than the TSS standards themselves at 3 locations: 1) East Fork Carson River at Riverview; 2) Carson River at Mexican Gage; and 3) Carson River at Deer Run Road.

- Based upon NDEP monitoring, the highest median TSS and turbidity levels have occurred at the Mexican Gage site, with somewhat lower levels at Deer Run Road and Weeks Bridge. For the period April-June, the highest median TSS and turbidity levels were at Weeks Bridge.

- The East Fork Carson River is a larger contributor of TSS and turbidity than the West Fork.

- Kendall tau analyses indicated statistically significant relationships between TSS and flow; and turbidity and flow, with the highest Kendall tau values during the runoff season (April-June).

- Load duration curves showed that much of the excess load occurs within the 0 to 10% duration interval (high flow periods). It is concluded that addressing nonpoint sources loads produced during these high flow events may not be feasible.

Assessment of the Middle Carson River and Recommendations for the Purpose of Recovering and Sustaining the Riverine Ecosystem (Otis Bay, 2007)

The purpose of this study was to provide the BLM and others with land management recommendations as needed to "…preserve, enhance, and sustain the middle Carson River ecological system. However, recommendations are general in nature. As next steps, Otis Bay suggests that more detailed plans be developed for each segment.

Key Findings/Conclusions:

- Otis Bay concluded that "…[t]he river has changed from a meandering and braided river with many wetland areas, to a more uniform and straight river with higher banks and fewer wetlands."

- Major factors leading to the reduction of cottonwood groves and willow shrubs along the Carson River banks have been identified as: 1) reduction of streamflows during late summer and fall; 2) channel straightening and deepening; and 3) expansion of invasive species.

- Otis Bay recommends that a river corridor and buffer be maintained "…that is sufficiently wide to allow the river to meander, to absorb and dissipate the energy of flood waters, to reduce flood peaks, to enhance water quality, and to provide natural habitats for birds, wildlife and people." For some reaches, restoration will be needed to re-establish a meandering form, and riparian and wetland vegetation. Increased late summer flows have been identified as also needed to support the restoration activities.

Characterization of Turbidity and Total Suspended Solids in the Upper Carson River, Nevada (Susfalk et al., 2008)

The overall purpose of this study was to improve understanding of the TSS and turbidity levels in the Carson system from Carson City upstream. To date, all existing TSS and turbidity data were from grab samples taken monthly or less frequent making it impossible to estimate the duration of high TSS/turbidity events. The project involved: 1) establishment of continuous turbidity monitoring stations at four locations between March 2004 and October 2006; 2) develop TSS-turbidity regression relations and estimate TSS concentrations during March 2004 through October 2006 based upon the turbidity data; and 3) develop TSS-flow and turbidity-flow regression equations and estimate historic turbidity and TSS concentrations and loads for 1995 through 2006 based upon streamflow.

Key Findings/Conclusions:

- During the monitoring period, turbidity levels and TSS concentrations (and the associated loads) in the West Fork at Diamond Valley Road were significantly lower than in the East Fork at Washoe Bridge. The same held true for the 1995 and 2006 period of estimated levels.

- Plots of measured turbidity and flow indicated hysteresis behaviors in the data, with higher turbidity levels during the rising limb of a hydrologic event than those experienced at the same flow on the falling limb. The turbidity-flow regressions underestimate turbidity levels during high flows and do not account for the hysteresis phenomenon.

Additional information related to this project has been incorporated in the following DISCUSSION section.

DISCUSSION

TSS and Turbidity Levels in the Carson system

NDEP and others have been collecting TSS and turbidity data at a variety of sites on the Carson system. (Figure 2 and Table 3). Following is a summary of TSS and turbidity levels and their spatial and temporal variability, based upon these data.

Table 3. Selected Sampling Locations on the Carson River System

ID	Description	Agency ID	Agency
WF-1	West Fork Carson River at Paynesville	C8	NDEP
		Diamond Valley	DRI
WF-2	West Fork Carson River at Muller Lane	C14	NDEP
		CVWF	CVCD
EF-1	East Fork Carson River at Riverview Mobile Home Park	C9	NDEP
		CVWB	CVCD
		Riverview	DRI
EF-2	East Fork Carson River at Highway 88	C16	NDEP
		CV88	CVCD
EF-3	East Fork Carson River at Muller Lane	C15	NDEP
CR-1	Carson River at Genoa Lane	C3	NDEP
CR-1a	Carson River at Genoa Lake Golf Course (below Brockliss Slough)	Genoa Lakes	DRI
CR-2	Carson River at Cradlebaugh Bridge	C2	NDEP
CR-3	Carson River at Mexican Gage	C13	NDEP
		CVMG	CVCD
CR-4	Carson River at Deer Run Road (New Empire)	C1	NDEP
		CVDR	CVCD
CR-4a	Carson River at Brunswick Canyon	Brunswick Canyon	DRI
CR-5	Carson River at Dayton Bridge	C11	NDEP
		DVD	DVCD
CR-6	Carson River at Weeks	C10	NDEP
		DVW	DVCD

NOTE
NDEP = Nevada Division of Environmental Protection
CVCD = Carson Valley Conservation District
DVCD = Dayton Valley Conservation District
DRI = Desert Research Institute

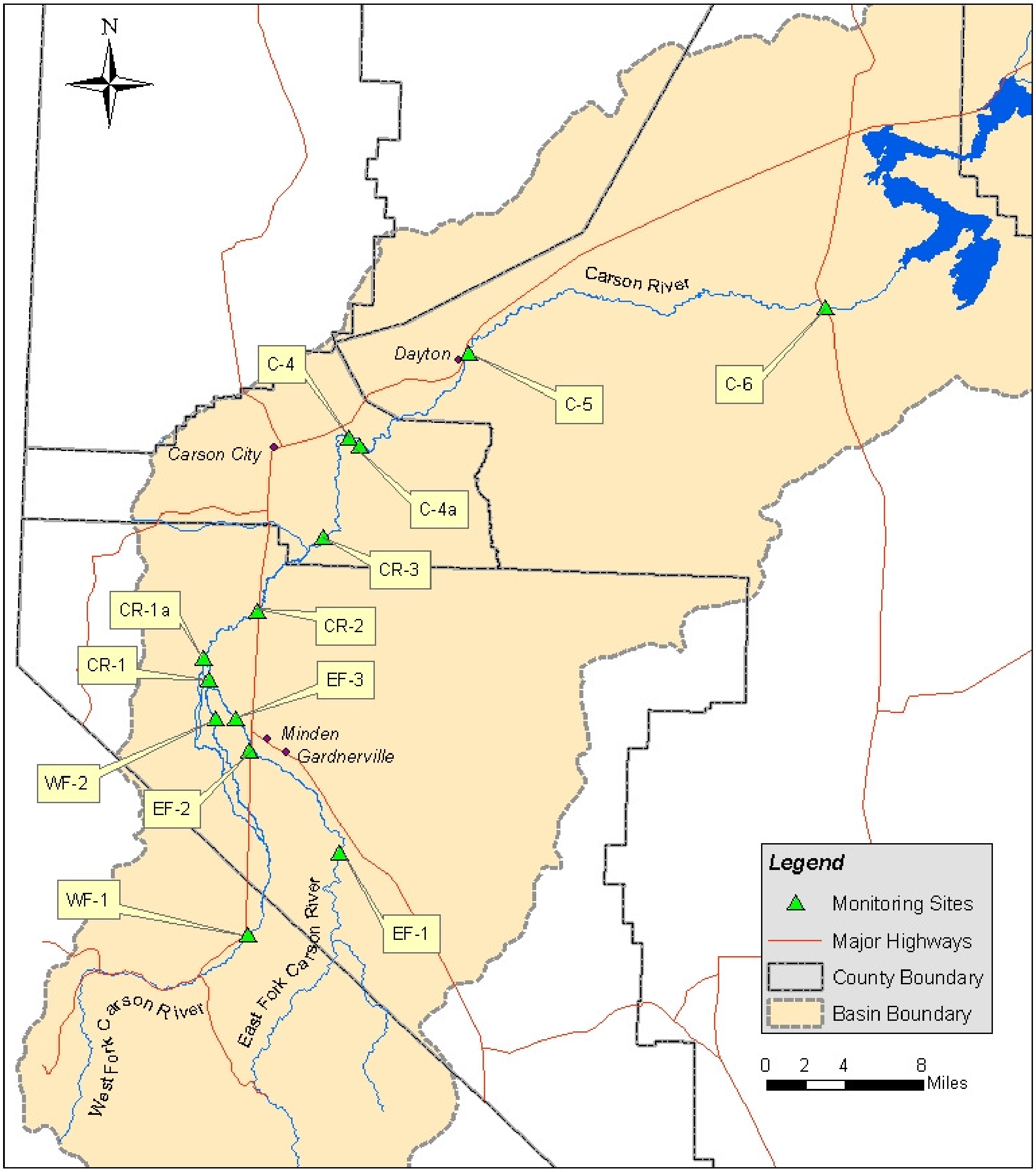
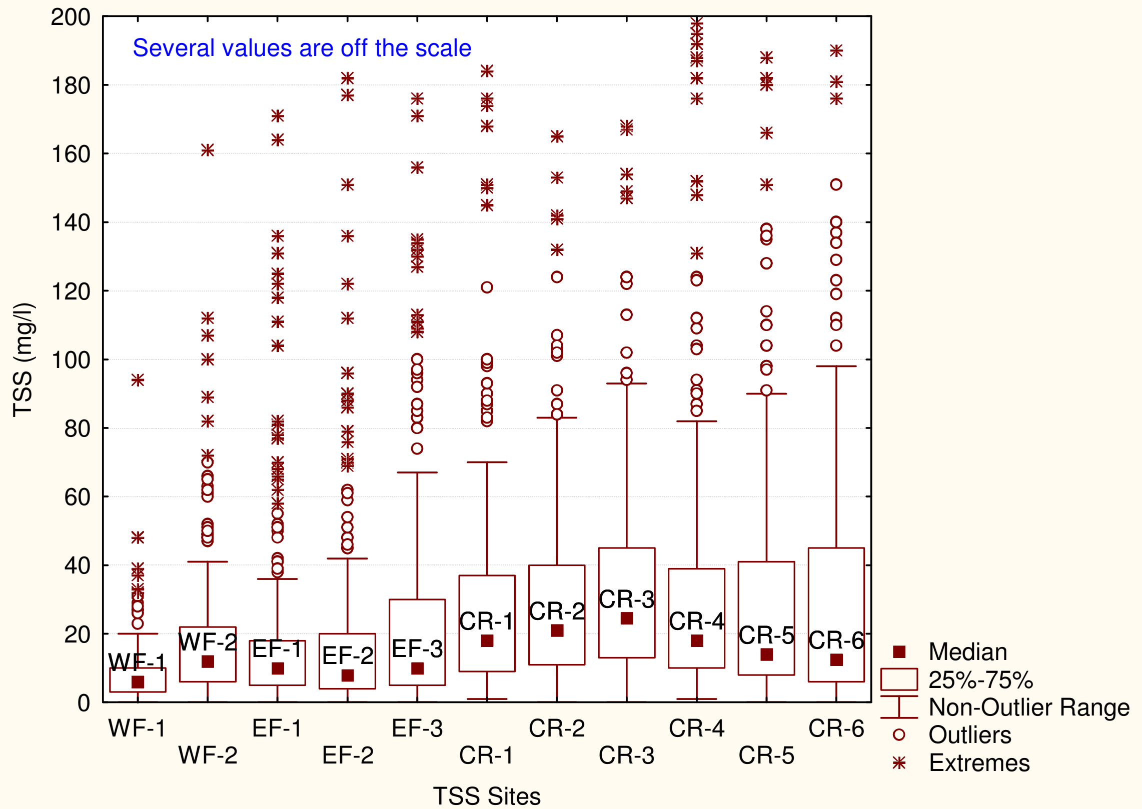


Figure 2. Selected Monitoring Sites

Spatial Variability

TSS and turbidity levels vary throughout the system, in part due to variations in watershed and channel erosion loadings. NDEP/CVCD/DVCD data shows the lowest median TSS and turbidity levels typically occur on the West Fork Carson at Paynesville (WF-1) and the highest occur on the Carson River at Mexican gage (CR-3) (Figures 3 and 4). It is interesting to note that these data show that the median TSS and turbidity levels on the East Fork where it enters Carson Valley (EF-1) are generally higher than on the West Fork prior to entering Carson Valley (WF-1). Susfalk et al. (2008) load estimates (Table 4) show similar results for 2005 and 2006, with significantly more TSS load per watershed area coming out of the upper East Fork watershed compared to the upper West Fork watershed.

Figure 3. TSS Levels (1969-2007)



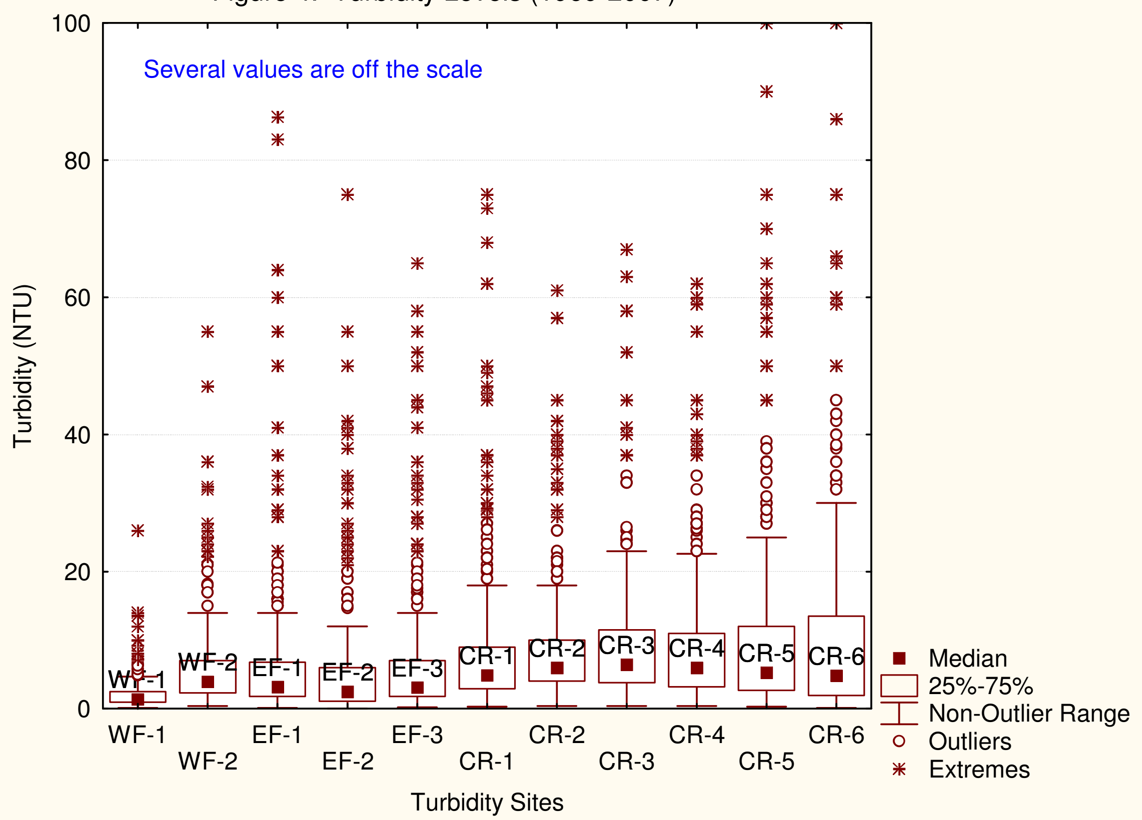


Figure 4. Turbidity Levels (1969-2007)

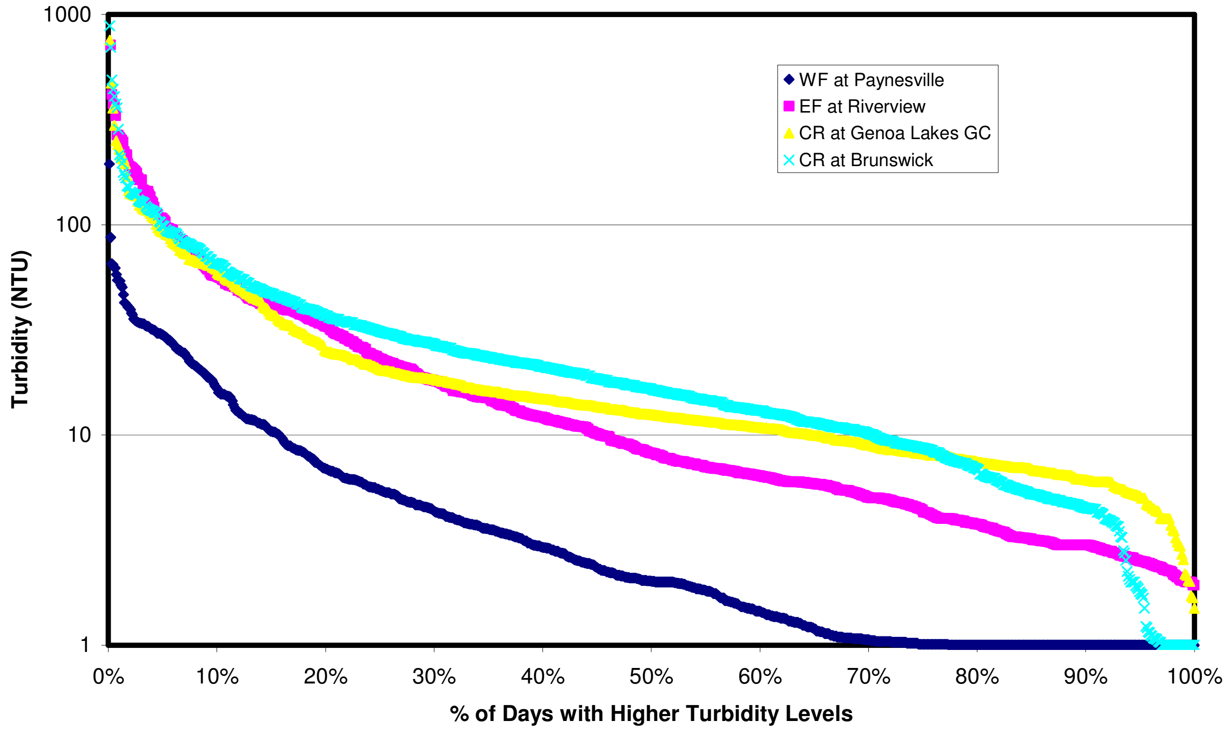
Table 4. TSS Loadings Estimated by DRI for 2004-2006

ID	Description	TSS Load, in 1 x 10^5 kg (TSS Load by watershed area, in 1 x 10^5 kg per square mile)		
		WY 2004	WY 2005	WY 2006
WF-1	West Fork Carson River at Paynesville	11 ± 13 (0.17)	22 ± 21 (0.34)	35 ± 30 (0.54)
EF-1	East Fork Carson River at Riverview Mobile Home Park	41 ± 156 (0.12)	468± 150 (1.31)	759 ± 637 (2.13)
CR-1a	Carson River at Genoa Lake Golf Course	50± 53 (0.07)	479± 131 (0.71)	722 ±194 (1.07)
CR-4a	Carson River at Brunswick Canyon	81± 29 (0.08)	443± 229 (0.46)	1072 ± 37 (1.12)

Note: + or - = 95% Prediction interval

Turbidity levels as measured by Susfalk and others (2008) showed significantly lower levels on the West Fork at Paynesville than on the EF Carson at Riverview (Figure 5). On the West Fork at Paynesville, the turbidity standard (10 NTUs) was exceeded in only about 15% of the samples, while the standard was exceeded in about 50% or more of the samples at the other 3 locations.

Figure 5. Turbidity Duration Curves - 2004-06



Literature indicates that the severity of sediments effects on aquatic life is related not only to the concentration but also to the exposure duration (Newcombe and MacDonald, 1991). As summarized in Table 5, turbidity data collected by Susfalk and others (2008) show that the turbidity standard exceedances on the East Fork Carson (EF-1) and the Carson River (CR-1a and CR-4a) were more frequent and of longer duration than on the upper West Fork Carson (WF-1).

Table 5. Summary of Turbidity Exceedance Events – 2004-06

Parameter	WF-1: WF at Paynesville	EF-1: EF at Riverview	CR-1a: CR at Genoa Lakes	CR-4a: CR at Brunswick
Number of WQS Exceedance Events	19	25	31	27
Maximum Duration (days)	34	157	96	166
Median Duration (days)	3	3	6	5
Average Duration (days)	7.7	15.9	14.5	27.9

Temporal and Flow Variability

Not surprisingly, Kendall's tau correlation analyses by NDEP (2007) indicate a positive relationship between TSS and flow, and between turbidity and flow. In other words, TSS and turbidity levels tend to increase as flows increase. As a result, standards exceedances generally occur during high flows which are most common during April through June (NDEP, 2007). However, relationships between flow and TSS/turbidity are not always simple. Susfalk and others (2008) found hysteresis occurring in the turbidity versus relationships (Figure 6). In other words, turbidity has a different relationship with flow during the rising limb of a runoff hydrograph compared to the falling limb, typically with higher levels during the rising limb period than during the falling limb for the same flow. Susfalk and others were not able to identify any hysteresis in the TSS-flow relationships due to the lack of data. However, Katzer and Bennett (1980) found similar hysteresis effects between SSC (suspended sediment concentrations) and flow (Figure 7).

Figure 6. Hysteresis Relationship between Turbidity and Flow - Carson River at Brunswick Canyon (Susfalk, et al. 2008)

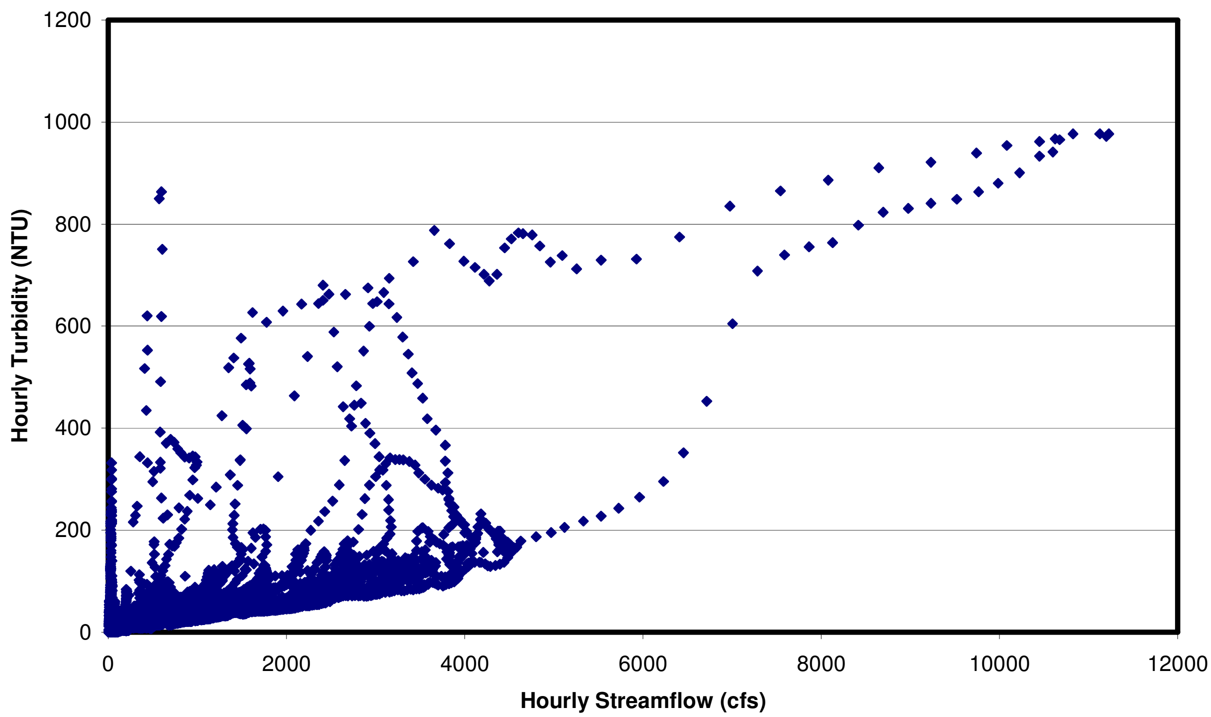
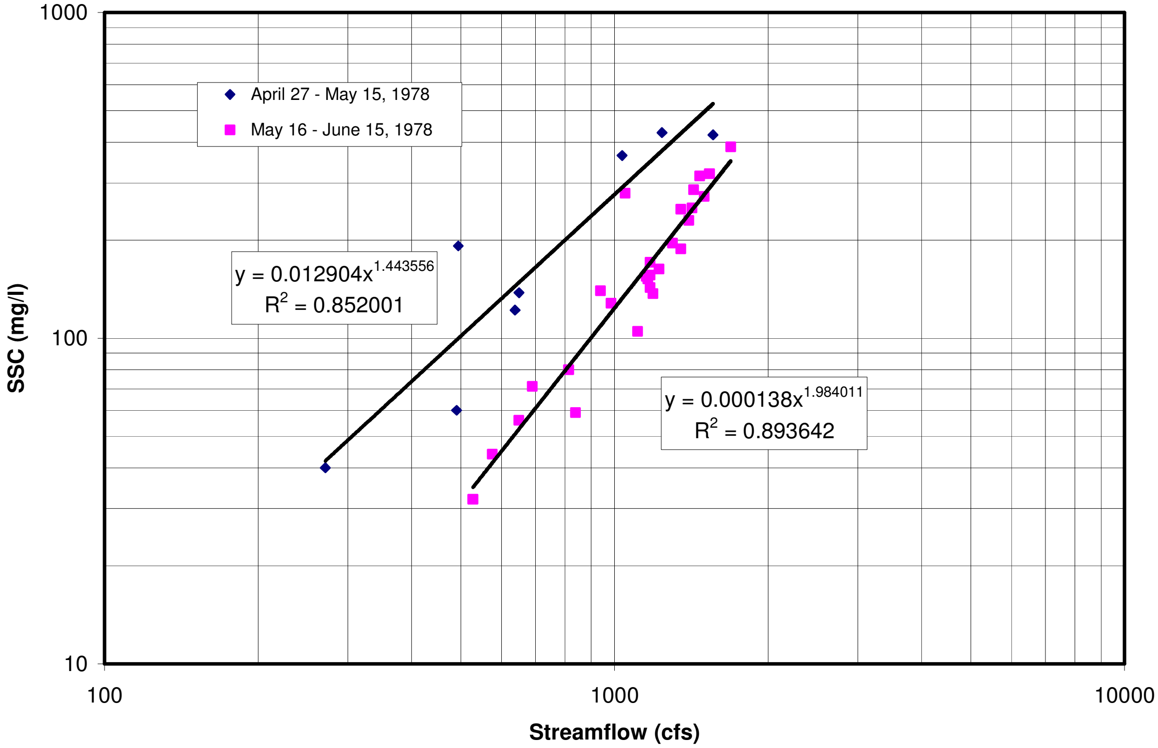


Figure 7 . EF Carson River at Highway 88 - SSC vs. Flow (1978)



Suspended Sediment Concentrations, Total Suspended Solids and Duration Effects

Suspended sediment concentration (SSC) in the water column is a common measure of sediment conditions in a stream. In fact, SSC may be the more appropriate metric for characterizing natural river water than TSS. TSS methods were originally designed for the analysis of wastewater and are not reliable techniques for analyzing natural river water (Gray et al., 2000). They conclude that the "…accuracy and comparability of suspended solid-phase concentrations of the Nation's natural waters would be greatly enhanced if all these data were produced by the SSC analytical method.

Literature indicates that the severity of SSC effects on aquatic life is related not only to the concentration but also to the exposure duration (Newcombe and MacDonald, 1991). Later, Newcombe (1997) concluded there is likely no sharply defined concentration or exposure duration above which fish are damaged. In an attempt to describe the gradient of impacts upon aquatic life, Newcombe (1997) developed a series of equations relating SSC concentrations and exposure duration to a severity of effects value (SEV) for various aquatic organisms and their life stages:

Juvenile and Adult Salmonids: $SEV = 1.0642 + 0.6068 * (\ln X) + 0.7384 * (\ln Y)$

Eggs and Larvae of Salmonids and Nonsalmonids: $SEV = 3.7466 + 1.0946 * (\ln X) + 0.3117 * (\ln Y)$

Adult Freshwater Nonsalmonids: $SEV = 4.0815 + 0.7126 * (\ln X) + 0.2829 * (\ln Y)$

Aquatic Invertebrates: $SEV = 4.3780 + 0.7630 * (\ln X) + 0.4578 * (\ln Y)$

Where
Ln X = natural logarithm of duration (in hours)
Ln Y = natural logarithm of SSC (in mg/l)

The resulting SEV varies from behavioral effects such as avoidance to lethal effects (Table 6).

Table 6. Severity of Effects Values and Description

SEV	Description of Effect
Nil effect	
0	No behavioral effects
Behavioral effects	
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response
Sublethal effects	
4	Short-term reduction in feeding rates; short-term reduction in feeding success
5	Minor physiological stress; increase in rate of coughing
6	Moderate physiological stress
7	Moderate habitat degradation; impaired homing
8	Indicators of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition
Lethal and paralethal effects	
9	Reduced growth rate; delayed hatching; reduced fish density
10	0-20% mortality; increased predation; moderate to severe habitat degradation
11	20-40% mortality
12	40-60% mortality
13	60-80% mortality
14	80-100% mortality

While an examination of both concentrations and duration are most appropriate for accessing impacts, such an effort requires rather detailed water quality, especially in characterizing duration. Unfortunately, limited SSC data exists on the Carson system. Some of the most detailed SSC data were collected on the East Fork Carson River in 1978 by the USGS (Katzer and Bennett, 1980). During the 1978 spring runoff, USGS sampled for SSC at a number of locations on the East Fork, with the Highway 88 site having the most SSC data and concurrent flow. A plot (Figure 7) of the SSC and flow data show that higher SSC levels were experienced during the earlier part of the runoff (pre-May 15) than later in the runoff for a given flow. Katzer and Bennett (1980) stated that this was a common phenomenon in river systems. In fact, Susfalk et al. (2008) found similar conditions at four different monitoring locations.

By applying the regression equations in Figure 7 along with daily streamflow, daily SSC levels at Highway 88 were estimated for 1978 (Figure 8). From the estimated SSC levels, the number of continuous days SSC exceeded various thresholds (ranging from 50 to 500 mg/l) was estimated. By applying Newcombe's equations to these paired values of SSC and duration, SEV values were found to range from 5.9 to over 13 (Table 7) with the "Eggs and Larvae of Salmonids and Nonsalmonids" SEV levels well into the lethal range ($\geq$ 9). Juvenile and Adult Salmonid SEV level were the lowest but still extend into the upper sublethal range ($\geq$ 7).

Figure 8 . EF Carson River at Hwy 88 - Estimated and Measured SSC Levels - 1978

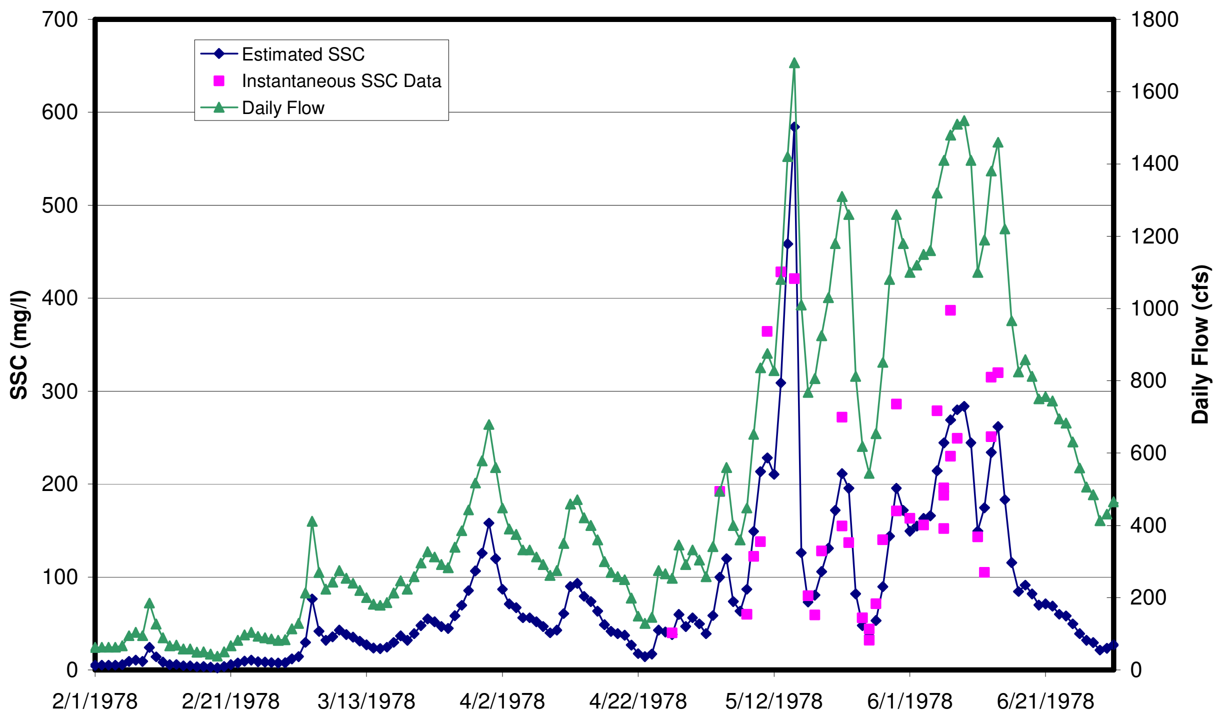


Table 7. SEV Ranges for SSC Levels in EF Carson River at Highway 88 during 1978

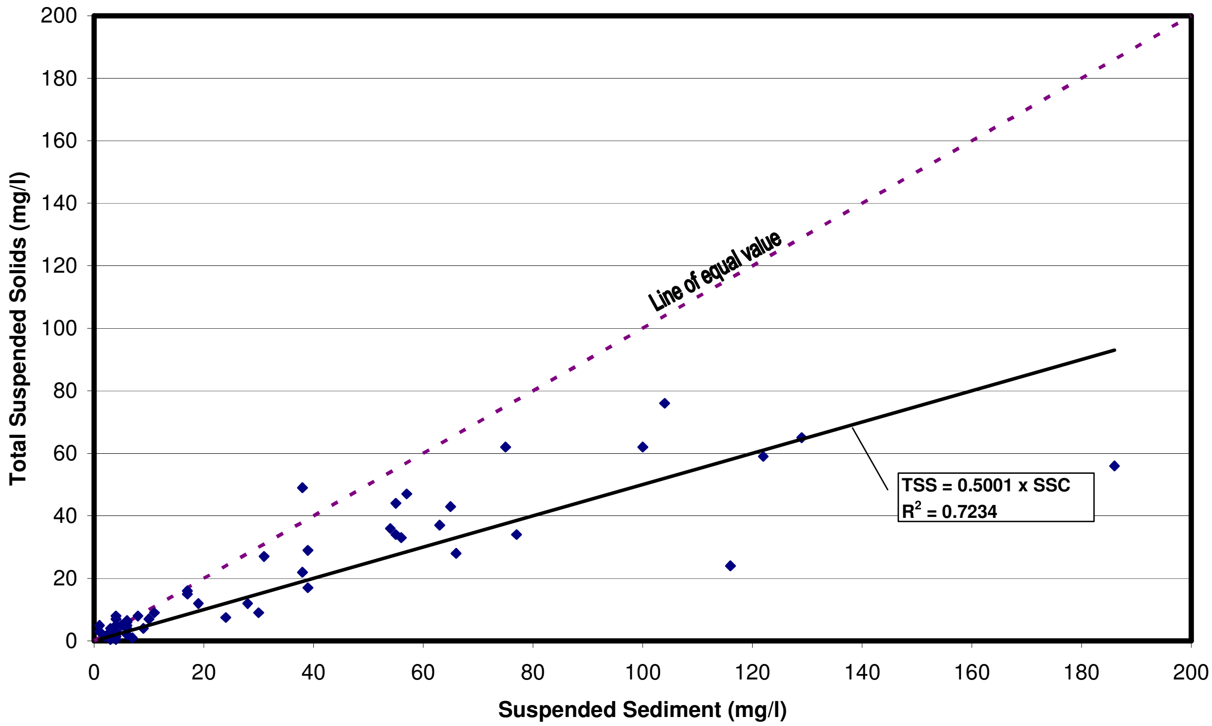
Aquatic Life	SEV Range
Juvenile and Adult Salmonids	5.9 – 8.2
Eggs and Larvae of Salmonids and Nonsalmonids	8.5 – 11.9
Adult Freshwater Nonsalmonids	7.5 – 9.7
Aquatic Invertebrates	8.6 – 11.2

It needs to be recognized that Newcombe's approach does not directly recognize a gradient of aquatic uses (example: from exceptional coldwater fishery to coldwater fishery). The Clean Water Act and guidance allows for the establishment of a gradient of aquatic uses. For example, headwater areas could be identified as exceptional coldwater fisheries, while lower stream reaches could be characterized simply as coldwater fisheries. Each could have different water quality standards. Under this type of gradient of aquatic uses, higher SEV values may be acceptable for the coldwater fishery while lower SEV may be desired for the "exceptional" fishery.

Suspended Sediment Concentrations (SSC) & TSS

SSC and TSS are often used interchangeably, however Gray et al. (2000) have shown there can be a significant different between SSC and TSS for the same sample. Gray et al. found that, for the same sample, SSC values tend to be greater than the TSS values when the percentage of sand (>0.0625 mm) in the sample exceed 25%. An analysis of SSC-TSS paired data (54 pairs) from Alvarez and Seiler (2004) suggests that TSS levels can be roughly ½ of SSC levels in the Carson system (Figure 9). Of the over 500 suspended sediment samples collected over the years from stateline to Lahontan Reservoir, about 96% contained sand at levels greater than 25%, and 75% of the samples contained over 50% sand. The high level of suspended sand in the Carson system would likely explain the difference between SSC and TSS values.

Figure 9. SSC vs. TSS - East Fork, West Fork and Mainstem Carson River above Lahontan Reservoir (2000-02)



Watershed Conditions

As discussed above, Susfalk et al. (2008) showed that the upper East Fork Carson watershed produces more TSS load per AF than the upper West Fork. The Alpine Watershed Group (2004) concluded that the East Fork has significantly higher natural sediment transport than the West Fork. They found extensive areas in the Upper East Fork watershed with erosion potential (Figure 10). According to U.S. Forest Service (2007), the East Fork drainage is dominated by volcanic rock that is highly erodible, with many of the channels incised into this material. They also stated that slopes adjacent to the streams tend to be extremely steep with occasional landslides contributing to sediment loads in the river.

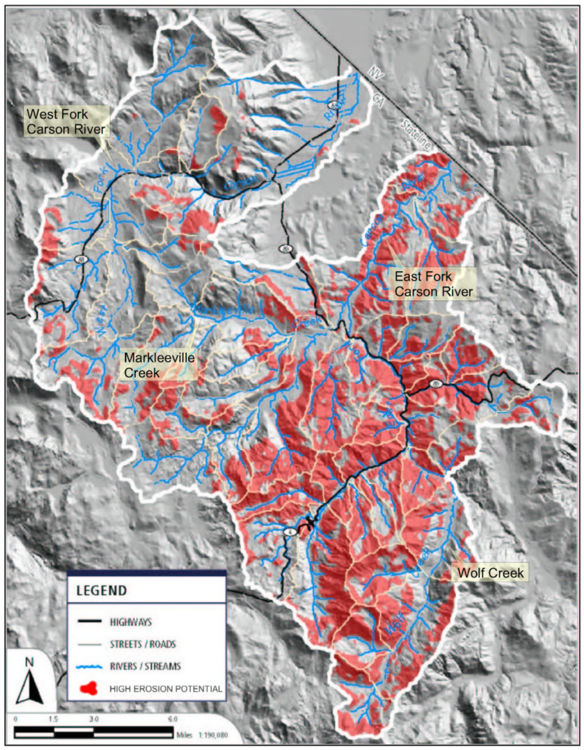


Figure 10. Erosion Potential in Upper West Fork and East Fork Carson Watersheds (from Alpine Watershed Group, 2004)

It is unknown how wildfires may have contributed to higher sediment loads out of the upper East Fork watershed. However, data compiled by Alpine Watershed Group shows that more area has burned in the upper East Fork drainage than in the West Fork since the 1940s (Figure 11).

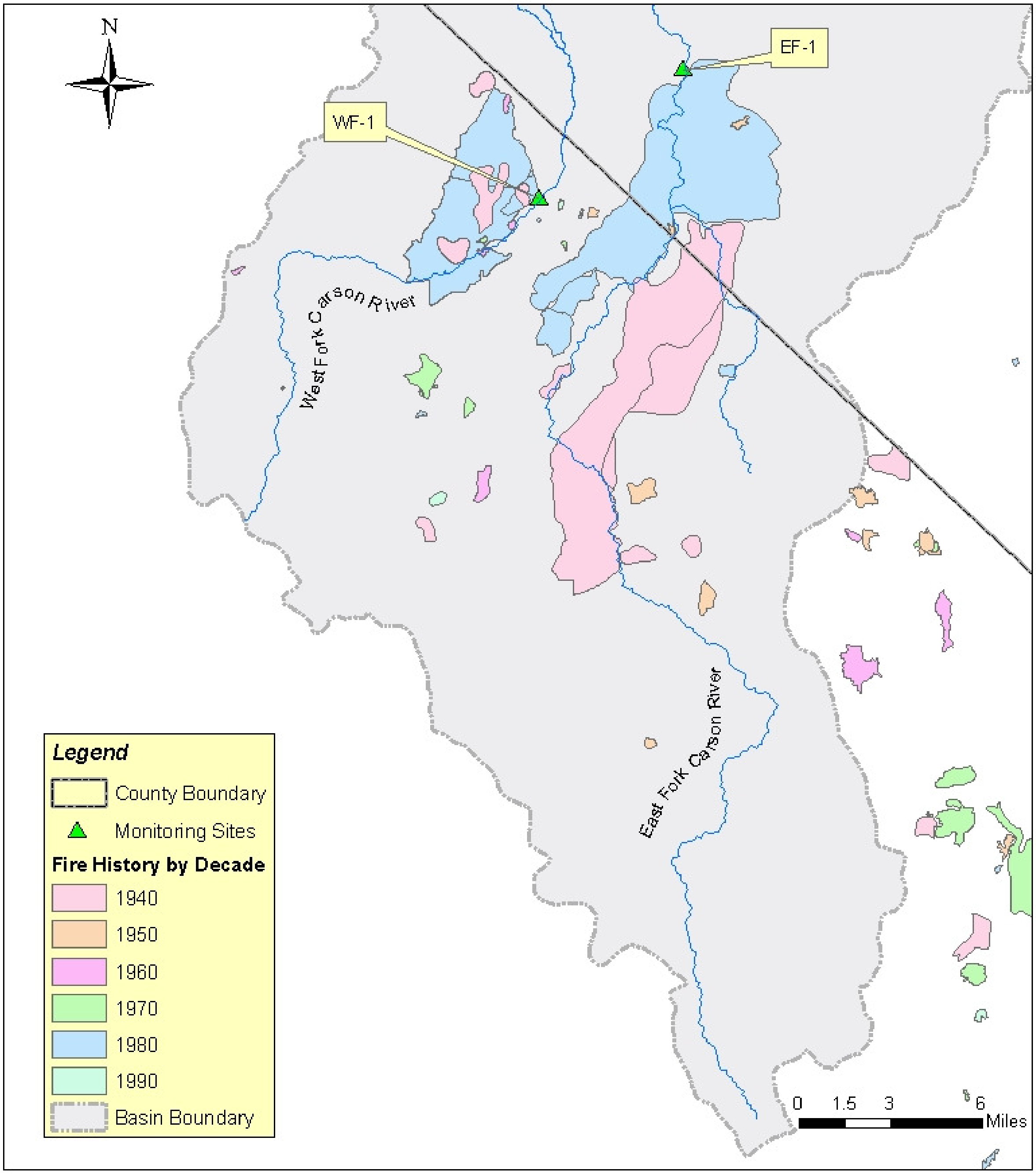


Figure 11. Wild Fires in the Upper Carson Watershed (Alpine Watershed Group, 2004)

Episodic Events

Occasional episodic events contribute sediment to the river channel. USFS (2007) has identified a large landslide near the confluence of the East Fork Carson River and Wolf Creek dating back to the 1960s. The landslide is still active and periodically contributes sediment loads to the East Fork. According to the USFS (2007), there is evidence that during the 1997 flood the landslide temporarily blocked the entire channel of the East Fork.

During August 2005, thunderstorms in the Pine Nuts Mountains east of Carson City resulted in some significant gully erosion and large sediment loading to the river (Figure 12). Subsequent, high runoff during the next year transported much of this sediment downstream.

Figure 12. Sediment Deposition in the Carson River between Mexican Dam and Lloyd's Bridge

Channel Conditions

Interfluve (1996) has categorized the stability of the Carson River as general poor as indicated by many miles of eroding banks, large sediment supply, and a degraded riparian corridor. Over the last 150 years, the Carson River and its forks have been subjected to a series of human-induced changes that have had long term impacts on the stability and health of the river channel and its riparian corridor. For example during the Comstock mining era, timbers were logged from the Upper East Fork Carson River to support underground mine construction. The logs were then floated down the East Fork (Figure 13) and the main Carson River to Empire City (near Deer Run Road) where they were removed and hauled to Virginia City (Horton, 1997).

Figure 13. Wood Drive on East Fork Carson River near site of Ruhenstroth Dam, 1888 (Photograph by C.E. Peterson)

Channelization has had a significant impact upon the health of the river channel. In 1965, the Bureau of Reclamation channelized over half (70 out of 114 mile) of the Carson River between Stateline and Lahontan Reservoir. Efforts including channel straightening , levee construction, channel relocation, and expansion of channel cross-sectional area (Interfluve, 1996). Figure 14 depicts how channelization near Genoa Lane resulted in a 20% reduction in channel length between 1938 and 2004.

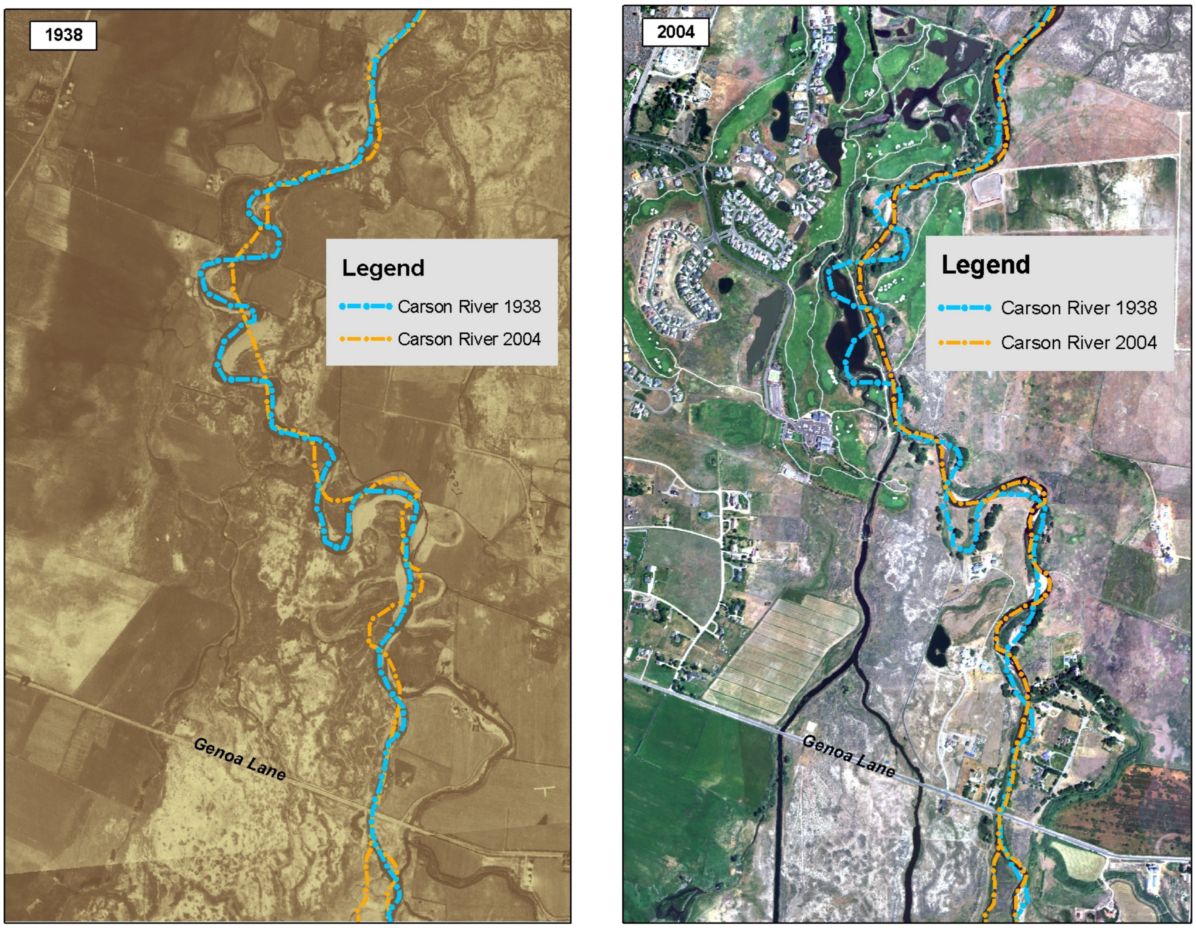
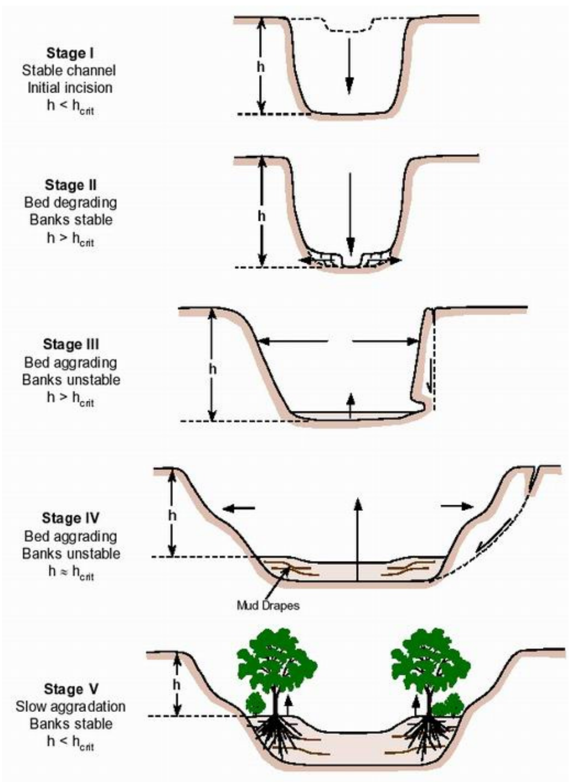


Figure 14. Carson River Channel Alignment Change from 1938 to 2004

A common response to channelization is increased erosion of the channel bed, leading to incisement and increased channel bank failure. Figure 15 depict the possible stages following channel incisement. As a stream becomes incised, the banks become more unstable, groundwater levels drop, the floodplain is not as accessible by high flows, and habitat for vegetation becomes limited; contributing to sediment load in the stream. Stage V shows the establishment of a new, but lower floodplain, once a new "equilibrium" is reached.

Figure 15. Stages in Channel Evolution following Encisement (from City of Austin, 2004)



Interfluve (1996) surveyed channel conditions at numerous locations and concluded that "…enlarged and/or incised channels relative to historic conditions…" occur in virtually every section they evaluated. Figure 16 shows one example of incised channel conditions on the Carson River.

One method of quantifying incisement involves examining the hydraulic capacity of the channel as related to more natural, stable streams which can be expected to convey approximately the 1- to 3-year discharge event (Interfluve, 1996). Of the sections evaluated, Interfluve found some of the high channel capacities on the East Fork. Interfluve estimated that the East Fork Carson, which has been almost entirely channelized and significantly leveed, has channel capacities ranging from the 50- to the 100-year discharge. Since increased channel capacities limits the ability of flow energy to be dispersed across the floodplain, the channel bank are subjected to higher erosional forces than non-incised channels.

Figure 16. Incised Channel Conditions on Carson River above Highway 395

A long history of livestock grazing and irrigation use has resulted in areas with limited riparian vegetation. With limited riparian vegetation, streambanks have little protection from erosion further contributing to upstream sediment loads (Interfluve, 1996). Irrigation withdrawals have significantly affected late summer and fall flows, lead to the reduction in cottonwood and willows along the river (Interfluve, 1996; Otis Bay, 2007). Interfluve (1996) points out that the permanent irrigation diversion structures may be serving to prevent headcutting from migrating upstream.

Substrate Conditions

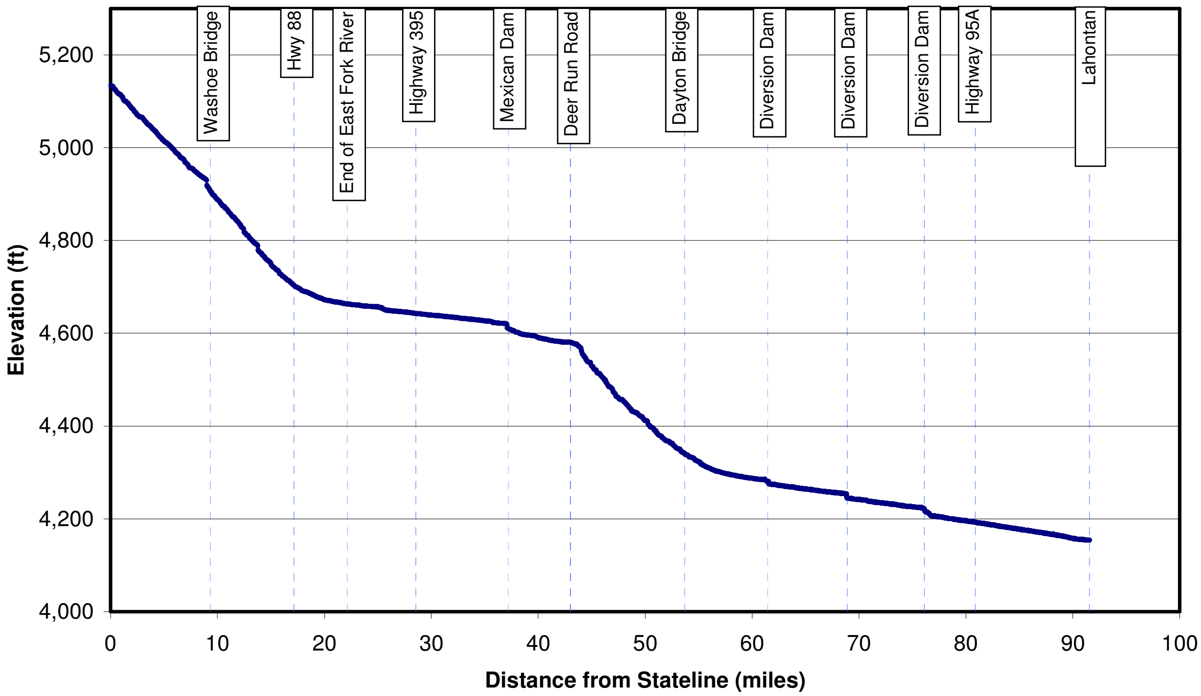
From Katzer and Bennett (1980), the median diameter (D_{50}) of the stream bed material on the East Fork above Muller Lane was found to range from 10 to 20 millimeters (medium to coarse gravel). Below Muller Lane, the D_{50} of the stream bed material dropped to about 0.5 millimeter (medium sand). These findings are comparable to those identified by Pahl (2006) as part of a relative bed stability investigation

Utilizing EPA's EMAP (Environmental Monitoring and Assessment Program) protocols, NDEP collected and analyzed field data to characterize substrate/stability conditions for various site within the Carson River system (from stateline to Lahontan Reservoir). Relative Bed Stability Indices suggest that the upper stream reaches (East Fork Carson River above Lutheran Bridge, West Fork Carson River above Brockliss Slough) are more stable than the lower sites; and that the sediment supply is not overwhelming the transport ability of the upper reaches. In the upper reaches, the substrate is dominated by gravel and cobble, with sand/silt comprises as little as 18% of the substrate material. However the conditions are drastically different in the lower Carson Valley and below. High levels of silt and sand (>80% of the substrate) were identified at: 1) Carson River above Highway 395; 2) Carson River above Mexican Gage; and 3) Carson River below Weeks Bridge (Highway 95A).

It is believed that the high levels of silt and sand in this stretch of the Carson River limit the habitat for fish spawning and other early life aquatic uses. Based upon a study of 562 stream in the northwest, Relyea et al. (2000) suggested that fine sediment (2mm or less) levels between 20-35% fines leads to changes to invertebrate communities. Based upon a literature review (Arizona Dept. of Environmental Quality, 2007), Arizona has established sediment level thresholds of <30% fines (2mm or less) for coldwater streams and <50% fines for warmwater streams. The Canadian Council of Ministers of the Environment (Canadian DFO, 2000) have recommended the following substrate thresholds: <10% of particles < 2mm, <19% of particles < 3 mm, and 25% of particles < 6.35 mm.

In general, the steeper the channel gradient the more coarse the streambed material. This seems to hold true for the Carson River. A plot of the water surface of the East Fork and main Carson River from the stateline to Lahontan Reservoir shows the great diversity of the stream gradients (Figure 17). Some of the flattest slopes occur between the start of the mainstem and Mexican Dam. In this area, silt and sand material make up to 80 to 98% of the substrate.

Figure 17. East Fork and Main Carson River Water Surface Profile from Stateline to Lahontan Reservoir



Review of Existing Water Quality Standards

As discussed earlier, Nevada has set Carson River TSS and turbidity standards (Table 1) with TSS values varying from 25 mg/l at the stateline to 80 mg/l for all other locations, and turbidity values set at 10 NTU for the coldwater reaches (above Deer Run Road) and at 50 NTU for the warmwater reaches (below Deer Run Road). Theoretically, these values were to have been set to protect the beneficial uses (aquatic life being the most restrictive in this case). For the Carson River, the aquatic beneficial uses have been defined as following (NAC 445A.146):

- Propagation of aquatic life, more specifically, the species of major concern are:
  - West Fork at stateline; East Fork from Stateline to Muller Lane
    - Rainbow trout and brown trout
  - West Fork below the stateline; East Fork from Muller Lane to confluence; Carson River above Highway 395
    - Catfish, rainbow trout and brown trout
  - Carson River from Highwy 395 to Mexican Gage
    - Rainbow trout and brown trout
  - Carson River from Mexican Gage to Deer Run Road
    - Smallmouth bass, rainbow trout and brown trout

- Carson River from Deer Run Road to Lahontan Reservoir
  - Walleye, channel catfish and white bass

Total Suspended Solids Criteria: Total suspended solids (TSS) numeric criteria were not added to the NAC until 1984 as part of significant revisions to the beneficial uses and criteria. Interestingly, the criteria that were proposed and ultimately adopted by the SEC included a TSS standard of 25 mg/l for both forks of the Carson at the stateline and for the Weeks-Lahontan Reservoir reach, and a much higher standard of 80 mg/l for the other reaches. According to the Rationale (NDEP, 1984), this difference in criteria is "…due to the excessively high [TSS] values determined for most reaches in the data analysis. Lower values are expected at the upper reaches due to high quality water, and in Lahontan due to the settling of solids in the upper end of the lake."

While not stated in the Rationale, it appears that the TSS criteria were derived from guidance provided in "Water Quality Criteria" (National Academy of Sciences, 1972) commonly referred to as the "Blue Book". According to the Blue Book, aquatic communities are provided a high level of protection with a TSS level of 25 mg/l and a moderate level of protection with a level of 80 mg/l.

Turbidity Criteria: The current turbidity criteria were added to the NAC in 1984 as part of a significant standards revision. As already discussed, the turbidity standards were set at to 10 NTUs for the coldwater fishery reaches (stateline to Deer Run Road) and 50 NTUs for the warmwater fishery reaches (Deer Run Road to Lahontan Dam). It appears these criteria were based upon recommendations in the "Report of the Committee on Water Quality Criteria" (FWPCA, 1968) commonly referred to as the "Green Book."

One problem with the existing criteria is the lack of consideration given to duration and frequency of TSS/turbidity levels. Newcombe and MacDonald (1991) concluded that concentrations alone were a poor indicator of suspended sediment impacts upon aquatic biota. They found the product of sediment concentration and duration of exposure to be a better indicator of impacts.

Another problem with the current criteria is that it focuses on only one type of impairment mode, i.e. effects of suspended material. Standards and impairment assessments should also consider substrate conditions and channel conditions (riffle/pool ratios, etc.) and their impacts upon the beneficial uses.

The TSS and turbidity standards for waters throughout the state are based upon outdated national guidance and may not be appropriate for all waters. The shortcomings of sediment-related criteria throughout the nation have been recognized by many. In 2003, EPA established 10 priority activities as part of a strategy for water quality standards and criteria. One of the priorities was: *Produce and implement a strategy for the development of suspended and bedded sediment (SABS) criteria*. In response, EPA (2006) has developed a framework document describing a process that states can use to develop appropriate SABS for beneficial use protection. At this time, it does not appear that EPA is considering the development of updated SABS criteria that states can use. Rather, states can choose to follow the framework to develop updated criteria themselves. Generally, the framework describes methods that can be used to establish criteria for 3 groups: 1) water column (turbidity, TSS, suspended sediment, water clarity, etc.), 2) bedded sediment (percent fines, embeddedness, substrate stability, etc.), and 3) response indicators (biological measures, eroding banks, etc.). The U.S. EPA Science Advisory Board concluded that multiple methods (rather than a single approach) may be more appropriate for SABS criteria development.

It should be recognized that Nevada regulations do provide some protection from bedded sediment through the narrative standards. NAC 445A.121(1) states:

> *Waters must be free from substances attributable to….controllable sources that will settle to form … bottom deposits in amounts … sufficient to interfere with any beneficial use of the water.*

However, Nevada has no defined protocols for implementing this narrative standard. Both Arizona and New Mexico have a similar narrative, yet they have developed implementation procedures (ADEQ, 2007; NMED, 2004). If desired, NDEP could develop similar implementation protocols to complement the use of TSS and turbidity standards.

Another problem with Nevada's SABS standards is the use of TSS criteria. As discussed earlier, SSC may be the more appropriate metric for characterizing natural river water than TSS. TSS methods were originally designed for the analysis of wastewater and are not reliable techniques for analyzing natural river water (Gray et al., 2000). They conclude that the "…accuracy and comparability of suspended solid-phase concentrations of the Nation's natural waters would be greatly enhanced if all these data were produced by the SSC analytical method.

A problem with the use of the existing turbidity criteria is in how turbidity levels are to be measured. Davies-Colley and Smith (2001) have found that turbidity measurements are strongly influenced by particle size among other factors. As a result, they have found that there can be appreciable differences in turbidity measurements using 2 different instruments on the same sample. These differences can be due to differences in optical design of the turbidity meters. They concluded that "…the scattering by suspended particles within the river waters interacts with different optical designs of the instruments to give different responses". To deal with problem, Davies-Colley and Smith (2001) recommend the type of instrument used for turbidity measurements should be specified.

Summary and Recommendations

1. Exceedances of turbidity and TSS standards are common occurrences throughout the Carson system, with higher frequency and duration at the lower sites. Sources include, but are not limited to, watershed erosion, including landslides, and channel erosion. Data indicate that the SABS levels coming out of the upper East Fork Carson drainage are higher than those from the upper West Fork Carson drainage.

2. High levels of fines exist in the stream substrate in many areas of the Carson system, with the higher levels in the lower Carson Valley and the Carson River above Lahontan Reservoir. In many areas, the stream substrate fines are well in exceedance of levels believed to be needed for a self-propagating fishery. However it is difficult to determine what level of fines is achievable. Due to low gradients, the substrates of some reach such as the lower Carson Valley may be naturally high in fines.

3. For the time being, NDEP should retain the current TSS and turbidity standards on the Carson system. However, NDEP should develop a long-term strategy for re-examining the existing TSS and turbidity criteria used statewide, and look at the possible inclusion of SSC and bedded sediment criteria. To support our impairment determination activities, NDEP should develop protocols for evaluating the narrative standard (NAC 445A.121(1)). Evaluation of SSC (level and duration) and stream substrate fines could be included in these protocols.

4. Future sampling and analyses activities need to recognize the hysteresis effects in the flow relationships. More frequent sampling during high flow events may be needed depending upon the purposes of the sampling.

References

Alpine Watershed Group. 2004. Upper Carson River Watershed Stream Corridor Condition Assessment.

Arizona Department of Environmental Quality. 2007. Narrative Bottom Deposits Standard Implementation Procedures for Wadeable, Perennial Streams.

Canadian Division of Fisheries and Oceans. 2000. Effects of Sediment on Fish and Their Habitat. DFO Pacific Region Habitat Status Report 2000/01.

Chapman, D.W. and K.P. McLeod. 1987. Development of Criteria for Fine Sediment in Northern Rockies Ecoregion. U.S. Environmental Protection Agency, Report 910/9-87-162, Seattle, Washington.

City of Austin, Texas. 2004. Watershed Protection, Stream Restoration Program Technical Memo.

Davis-Colley, R.J. and D.G. Smith. 2001. Turbidity, Suspended Sediment, and Water Clarity: A Review. Journal of American Water Resources Association, Vol. 37, No. 5, October 2001.

Federal Water Pollution Control Administration. 1968. Report of the Committee on Water Quality Criteria (Green Book).

Horton, G. 1997. Carson River Chronology. Nevada Division of Water Planning.

Inter-Fluve, Inc. 1997. Fluvial Geomorphic Assessment of the Carson River: Implications for Management of a Changing River. Prepared for Western Nevada Resource Conservation & Development, Inc.

Katzer, T. and J.P. Bennett. 1980. Sediment Transport Model for the East Fork of the Carson River, Carson Valley, Nevada. USGS Open File Report 80-160.

National Academy of Sciences. 1973. Water Quality Criteria (Blue Book).

Nevada Division of Environmental Protection. 2007. Total Maximum Daily Loads for Total Suspended Solids and Turbidity.

Nevada Division of Environmental Protection. 1984. Carson River Water Quality Standards Revisions Rationale.

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of Suspended Sediments on Aquatic Ecosystems. North American Journal of Fisheries Management 11:72-82, 1991.

Newcombe, C.P. 1997. Channel Suspended Sediment and Fisheries: a Concise Guide to Impacts – Draft. Ministry of Environment, Lands and Parks, British Columbia.

New Mexico Environment Department. 2004. Protocol for the Assessment of Stream Bottom Deposits (Sedimentation/Siltation) on Wadeable Streams.

Otis Bay Ecological Consultants. 2007. Assessment of the Middle Carson River and Recommendations for the Purpose of Recovering and Sustaining the Riverine Ecosystem. Prepared for the U.S. Bureau of Land Management.

Pahl, R.A. 2006. Carson River Relative Bed Stability Investigation. Nevada Division of Environmental Protection.

Pahl, R.A. 2004. History of Carson River Water Quality Standards. Nevada Division of Environmental Protection.

Relyea, C.D., C.W. Marshall, and R.J. Danehy. 2000. Streams Insects as Indicators of Fine Sediment. Stream Ecology Center, Idaho State University, Pocatello, Idaho.

Susfalk, R.B., B. Fitzgerald, A.M. Knust. 2008. Characterization of Turbidity and Total Suspended Solids in the Upper Carson River, Nevada. DHS Publication No. 41242. Desert Research Institute, Reno, Nevada.

U.S. Environmental Protection Agency. 2006. Framework for Developing Suspended and Bedded Sediments (SABS) Water Quality Criteria. EPA-822-R-06-001.

U.S. Environmental Protection Agency. 2003. Strategy for Water Quality Standards and Criteria: Setting Priorities to Strengthen the Foundation for Protecting and Restoring the Nation's Waters. Office of Water. EPA-823-R-03-010.

U.S. Forest Service. 2007. East Carson River Strategy. Carson Ranger District.

Waters, T.F. 1995. Sediment in Streams – Sources, Biological Effects and Control. American Fisheries Society Monograph 7.