USING SPREADSHEETS TO PREDICT STREAM SALINITIES IN THE YAMPA RIVER BASIN COAL FIELDS, NORTHWESTERN COLORADO[1]

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Abstract: Spreadsheets were used for predicting stream salinities in the Yampa River watershed. The concentration of total dissolved solids (TDS) represents salinity. The spreadsheets calculate TDS at 22 locations by summing the flow-weighted TDS values upstream from each point. The flow-weighted TDS values were compiled from publicly available monitoring data and from predicted future mining inputs. This spreadsheet method provides only a rough prediction of TDS concentrations because it does not precisely account for non-mining sources like irrigation and municipal runoff. Also, significant error is introduced by the differences in sampling times between locations. Spreadsheets were developed for eight different scenarios with various combinations of moisture conditions (precipitation), season (flow), and pumping of underground mine water to the surface. Calculated TDS values were posted on a GIS map of the watershed for visualizing mining impacts along stream segments. The eight scenarios for the spreadsheets predict the largest percentage increase in TDS occurs when there is uncontrolled mine pumping in a relatively dry year during low seasonal stream flow.

Additional Key Words: aquatic chemistry, cumulative hydrologic impact assessment, GIS hydrologic model, mass balance, mine drainage, mine pollution, numerical model, solute transport, salt loading stream model, spreadsheet hydrologic model

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Introduction

Coal has been mined since the late 1800s in the Yampa River Basin of northwestern Colorado. Currently eight mines are active in this basin (Fig. 1). Active and inactive surface and underground coal mines add dissolved solids to stream waters (Driver et al, 1984) via three main sources: a) surface runoff that percolates through coal spoil backfill then discharges from spoil springs; b) water pumped to the surface from the workings of underground mines, and c) surface runoff from lands disturbed during mining.

The main component of the dissolved solids is sulfate. Likely sources of this sulfate include oxidation of iron sulfides in spoil or waste rock and dissolution of calcium-sulfate or other sulfate minerals, as described for one mine in the area (Williams and Clark, 1994). High concentrations of dissolved solids (high salinities) can hinder plant growth when the water is used for irrigation (Maas, 1986). High concentrations of dissolved solids in stream water are an environmental concern in northwestern Colorado because stream water is widely used for irrigating hay fields.

The Coal Regulatory Program of the Colorado Division of Minerals and Geology assesses the impacts of active coal mining on streams in the state. The goal of each assessment is to identify existing impacts and predicted future impacts from active mines. Assessments are conducted both on a local scale for each mine and on a regional scale for all mines in a region.

One of the main pollutants evaluated in a regional assessment is total dissolved solids (TDS). TDS in the Yampa River Basin has previously been modeled using an accounting program (Parker and Norris, 1983). The Colorado Division of Minerals and Geology has modeled TDS in the basin using a DOS-based program developed by the U.S. Geological Survey, called BASIN (Gorham, 1996). The BASIN program determines flows and TDS concentrations at "nodes" along a stream, using the mass-balance equation (Burns, 1988). A "node" is the intersection of multiple sources of flow at a point in a stream.

The mass-balance equation for the case of a single mine input to a stream is:

$$\text{Downstream TDS} = \frac{(\text{Upstream TDS} \times \text{Upstream flow}) + (\text{Mine input TDS} \times \text{Mine input})}{(\text{Upstream flow} + \text{Mine flow})}$$

where TDS is the concentration of total dissolved solids (usually in milligrams per liter), and flows are usually in cubic feet per second.

Determining impact on TDS concentration in a stream from the input of a single mine is a simple matter of calculating the mass balance equation for a location downstream from the mine's input. Determining the concentration of TDS downstream from several mines in a watershed requires repeated calculations of the mass-balance equation at several locations in the watershed. The calculation farthest downstream represents the total cumulative impact of all mines in the watershed. Recently we began using a series of linked spreadsheets to perform the task, as described below. The motivation for changing from the BASIN program to a spreadsheet-based method was for the ease of use provided by a graphical user interface (BASIN is a DOS program), and the ability to link spreadsheets to a geographic information system.

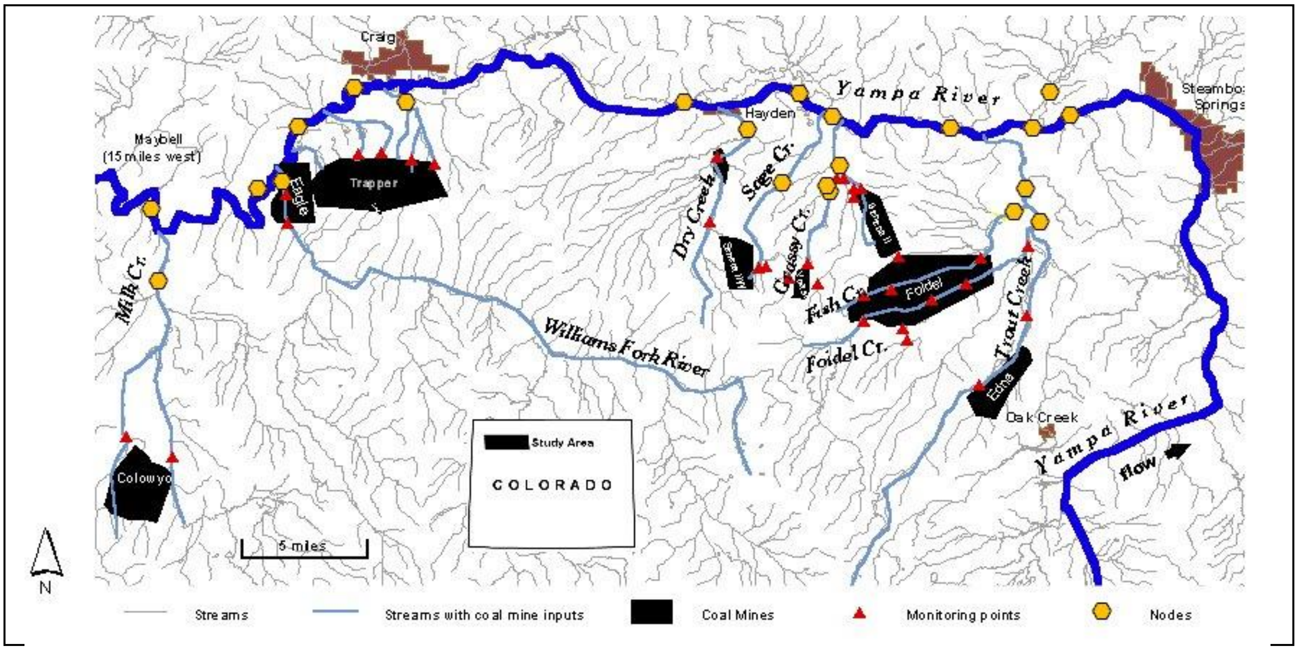


Figure 1 – Location map: Yampa River Basin, northwestern Colorado.

Methods

To simulate stream flows and TDS concentrations in the Yampa River Basin, spreadsheets were created for each of the seven tributaries of the Yampa River where coal mines are located. Each spreadsheet performs mass-balance calculations at several nodes located along the tributary. These tribuatary spreadsheets are linked to a master spreadsheet that performs mass-balance calculations for the mainstem of the Yampa River.

The eight spreadsheets (seven tributary and the mainstem) calculate flow and TDS at 22 locations (nodes) in the Yampa River Basin. The calculation for the node farthest downstream on the mainstem is the predicted cumulative flow and TDS resulting from inputs of all coal mines in the basin. Table 1 shows an example of the spreadsheet format for part of the mainstem of theYampa River.

Stream flow and TDS are simulated at a node by calculating the mass-balance equation using the TDS and flow values of projected future mine inputs, and a multi-year arithmetic average of instream flow and TDS values for the node. The instream averages used in the model were for a 12-year base-period, 1990 through 2001. This base-period spanned relatively wet and dry periods in the region, and precipitation near the historical average. Monitoring data were sparse or did not exist for some locations on small tributaries. These streams are ephemeral drainages, flowing a short time only after storms or during melt off of snowpack. Flow and TDS values were estimated for these locations based on similarities with nearby drainages.

The spreadsheets contain 16 instream monitoring points and 14 mine input points. Of the 14 mine inputs, 2 are pumping locations for underground mine water and the remainder are discharge monitoring locations.

Table 1 – Sample of spreadsheet.

Yampa River (mainstem)

Salt Loading Calculation

Scenario 1

Premining or active mining: Active
Month: August
Base years: 1990-2001
Underground pumping: No

Point	Location	Mines on stream segment	Flow (cfs)	TDS (mg/l)	Volume x Concentration (for calculation only, no units)	Data sources for flow and TDS values
Y1	Yampa River just above Elk River at USGS site 500	Above all mining	163.00	188	30644	USGS data - site 09239500
Y2	Elk River just above confluence with Yampa R.	Above all mining	147.00	76	11172	USGS data - site 09242500
Y3	Yampa River between Elk R. and Trout Creek	***Subtotal to this point***	310.00	135	41816	
T16	Trout Creek system total	Edna Mine, Foidel Creek Mine, part of Seneca II Mine	44.80	569	25473	Trout Creek spreadsheet
Y4	Yampa River between Trout and Grassy Creeks	***Subtotal to this point***	354.80	190	67289	
G11	Grassy Creek system total	Parts of Yoast and Seneca II Mines	0.40	2151	867	Grassy Creek spreadsheet
Y5	Yampa between Grassy Creek and Sage Creek	***Subtotal to this point***	355.20	192	68156	

Spreadsheet development involved the following steps:

1. Compile base-period data for each node (12 years of historical instream flow and TDS monitoring data from publicly available databases, mainly the U.S. Geological Survey).

2. Enter compiled data into database spreadsheet to generate base-period averages for each node.

3. Compile projected future coal mining inputs from mine operators' predictions in coal mining permit applications.

4. Enter base-period averages and projected future mining inputs into tributary and mainstem spreadsheets (generates spreadsheet results).

The following guidelines were applied when compiling base-period data for a node:

1. One data sample (flow and TDS) was compiled for each month in the base-year period.

2. The sample nearest the 15th of the month having both flow and TDS measurements was chosen.

3. If no data were available for a month, then the average of samples as near as possible to immediately before and after the month was used.

4. If only specific conductance (rather than TDS) was available for a month, the conductance (in micromhos/cm) was used as an indication of TDS by multiplying it by 0.60. Conversion factors ranging from 0.60 to 0.80 have generally been used for this conversion in northwestern Colorado (Driver et al, 1984).

The spreadsheets were used for estimating TDS for eight different scenarios (Table 2). The scenarios are combinations of the following conditions: moisture conditions (dry year versus average year), season (low stream flow versus high stream flow), and pumping of underground mine water (pumping versus not pumping). The scenario for average moisture conditions used all 12 years in the base-period. The scenario for a dry year used base-period data from only the three driest years in the base-period: 1994, 2000, and 2001. A scenario for years having above-average moisture conditions were not generated because the dilution capacity of streams is greatest then and consequently mining impacts would likely be minimized.

The scenarios for seasonal high and low stream flows were developed by using base-period data for only the months of April and August. These two months are of special interest because salt-loading impacts to streams can be greatest at those times. April and August are respectively at the beginning and the end of the northwestern Colorado irrigation season. In April there is intensive early-season flushing of dissolved solids from coal spoil, as shown in spoil spring monitoring data in annual hydrology reports from coal mines. (Salt loading from other sources was not considered.) By August the flushing has diminished, but stream flows are also approaching minimum flows, thus reducing the dilution capacity of streams. Irrigation is still occurring as late in the summer as August, creating high potential for some of the greatest impacts of the year from salt (TDS) loading.

The spreadsheet method can be expected to provide only a rough approximation of TDS concentrations because of several sources of error, including:

1. Unaccounted non-mining TDS sources in streams (crop irrigation, municipality waste-water discharges, natural gas well production discharges, etc.).
2. Differing sampling times of historical flow and TDS data used in the calculations.
3. Small sizes of datasets for historical flow and TDS at some of the stream locations.
4. Use of a single conversion factor basin-wide for converting specific conductance values to TDS values.
5. Presumption that TDS is conserved between sampling points and nodes.

Table 2 – Scenarios evaluated in spreadsheets.

Scenario	Flow	Moisture Conditions	Pumping
1	August (low)	Normal	No
2	August (low)	Normal	Yes
3	August (low)	Dry	No
4	August (low)	Dry	Yes
5	April (high)	Normal	No
6	April (high)	Normal	Yes
7	April (high)	Dry	No
8	April (high)	Dry	Yes

Back-testing of Method

The reliability of the spreadsheets for predicting flow and TDS was tested by entering monitoring data in spreadsheets for several past years. The TDS values predicted in the spreadsheets were compared to historical measured values from downstream locations. This "back-testing" of the spreadsheets was conducted for three locations, two on the mainstem of the Yampa River (Craig and Maybell) and one location on a tributary (Trout Creek, just above its confluence with the mainstem of the Yampa River). There were sufficient data for back-testing for April and August on the two mainstem locations, but there was enough data only for April at the Trout Creek location.

Fig. 2 and 3 show the results of back-testing. Generally, the spreadsheets underestimate flow in April and overestimate flow in August. The cause of this error is unknown, but may be due to unaccounted inflows from tributaries in April, and unaccounted irrigation withdrawals from streams in August.

In most cases predicted TDS was within 25% of the measured value. In three cases, however, predicted TDS differed from the measured value by approximately 50%. These poorly predicted cases are in April at the Craig and Maybell sites in 1997, and at Craig in 2001. The chief source of error appeared to be the widely differing times of sample collection at Maybell, Craig, and locations upstream. Measured TDS data at the Craig and Maybell mainstem sites were from late April when the Yampa River was swollen with relatively dilute snowmelt water, but the only TDS data available for making spreadsheet predictions were from early April before significant snowmelting had occurred. On Trout Creek, August flows are significantly overestimated in two of the four years back-tested, but TDS is fairly well predicted as predicted TDS is always within 28% of measured TDS (Fig. 4).

Correlation between predicted TDS and measured TDS was higher for August than for April (Table 3). Correlation was highest at the Maybell location, the farthest downstream location.

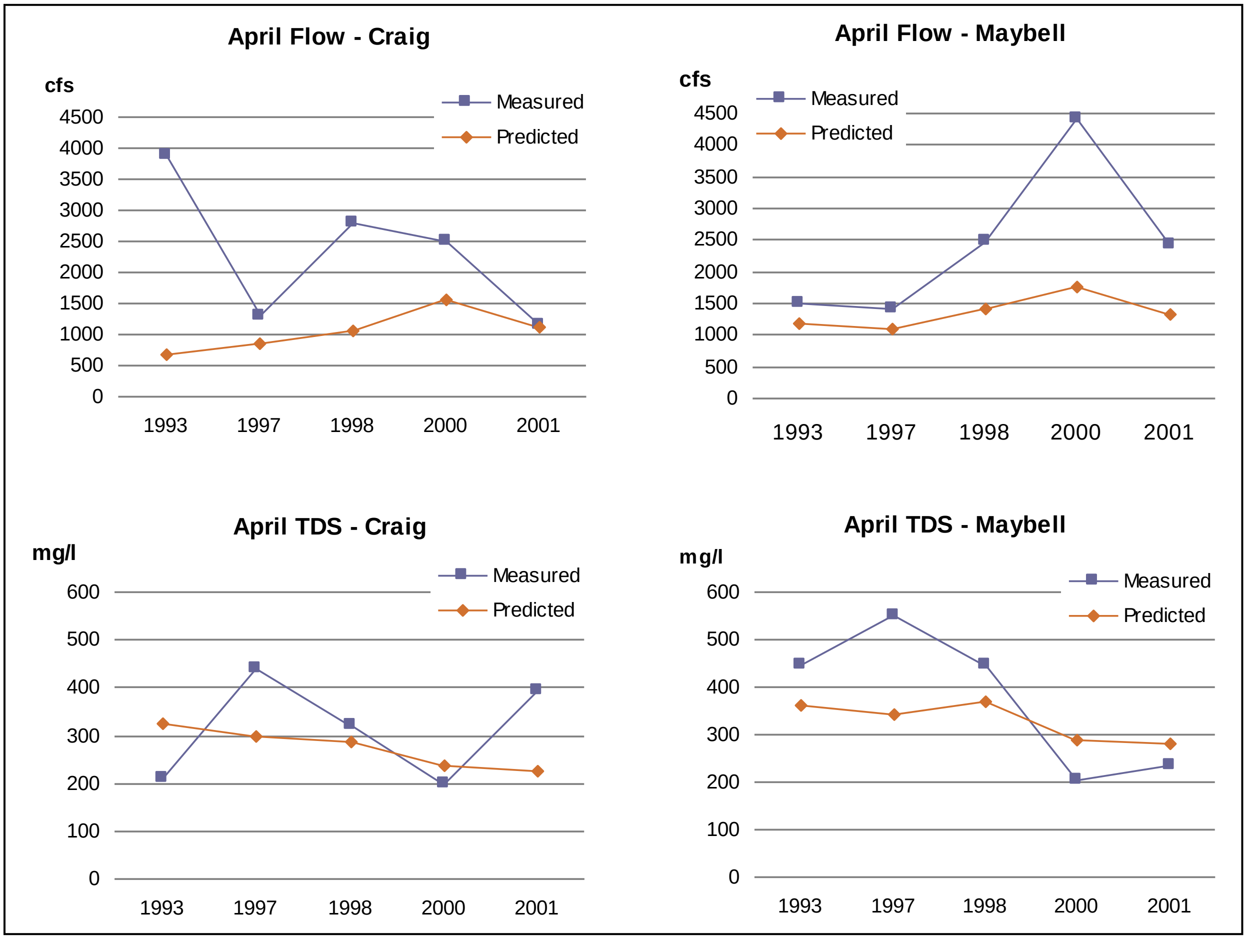
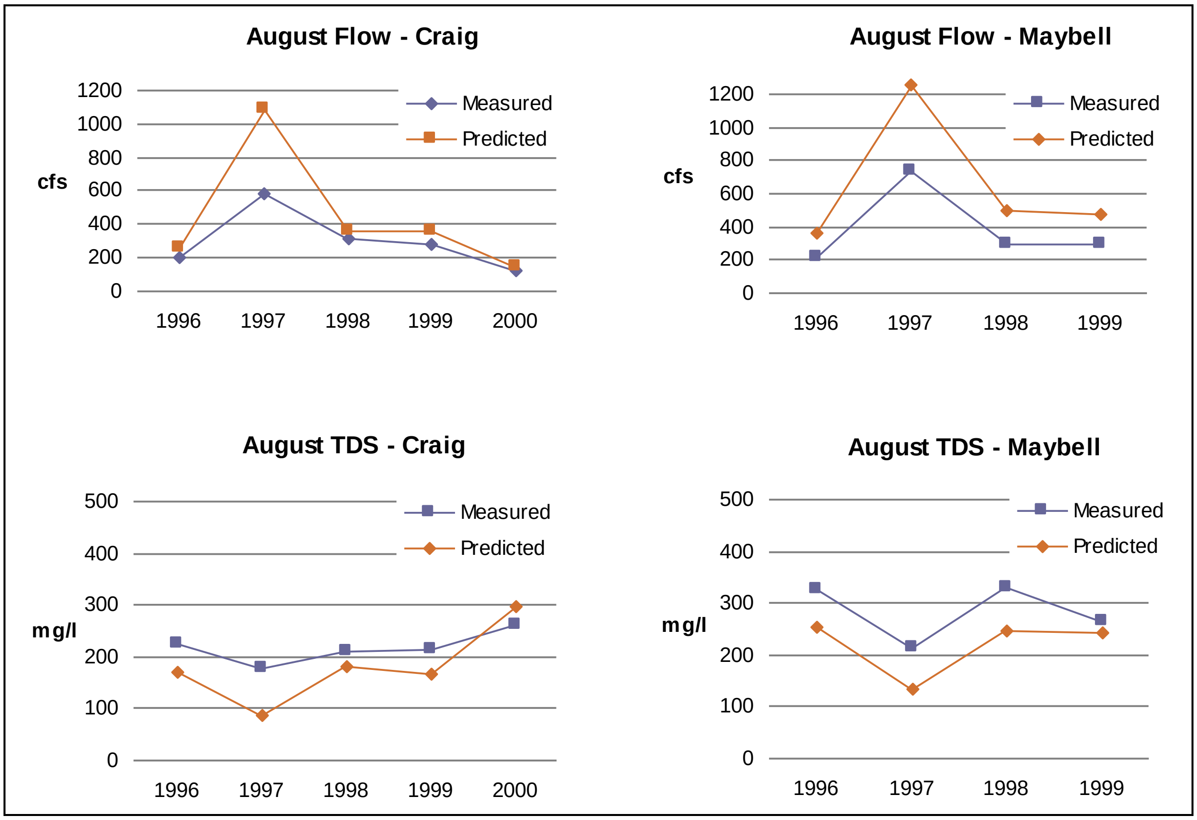


Figure 2 – Back-testing results for April at Craig and Maybell. (Comparisons for years 1994 through 1996, and 1999, were not possible due to lack of data.)

Table 3 – Correlation coefficients of back-testing results.

	August		April	
	Flow	TDS	Flow	TDS
Yampa River - Craig	0.98	0.97	-0.11	-0.24
Yampa River - Maybell	1.00	0.87	0.86	0.99
Trout Creek	no data		0.93	-0.43



August Flow - Craig

August Flow - Maybell

August TDS - Craig

August TDS - Maybell

Figure 3 – Back-testing results for August at Craig and Maybell.

Spreadsheet Predictions for Eight Scenarios

The only streams having more than one node are the Yampa River mainstem and two of its tributaries, Trout Creek and Grassy Creek. Any regional impact from a single-node stream is accounted for in the Yampa River mainstem; therefore, discussion of results will focus on the mainstem of the Yampa River. Spreadsheet results for the mainstem are summarized in Table 3 and Fig. 5, below.

In all scenarios considered, the predicted TDS in the Yampa River mainstem roughly doubles between the farthest upstream and downstream locations in the study area (Table 3 and Figure 5). TDS significantly increases at two locations, immediately downstream from nodes Y3 and Y8. The two increases occur at the Yampa's confluence with major tributaries, Trout Creek and the Williams Fork River. The increases appear independent of mine pumping because all scenarios show increases, although pumping appears to augment the increases.

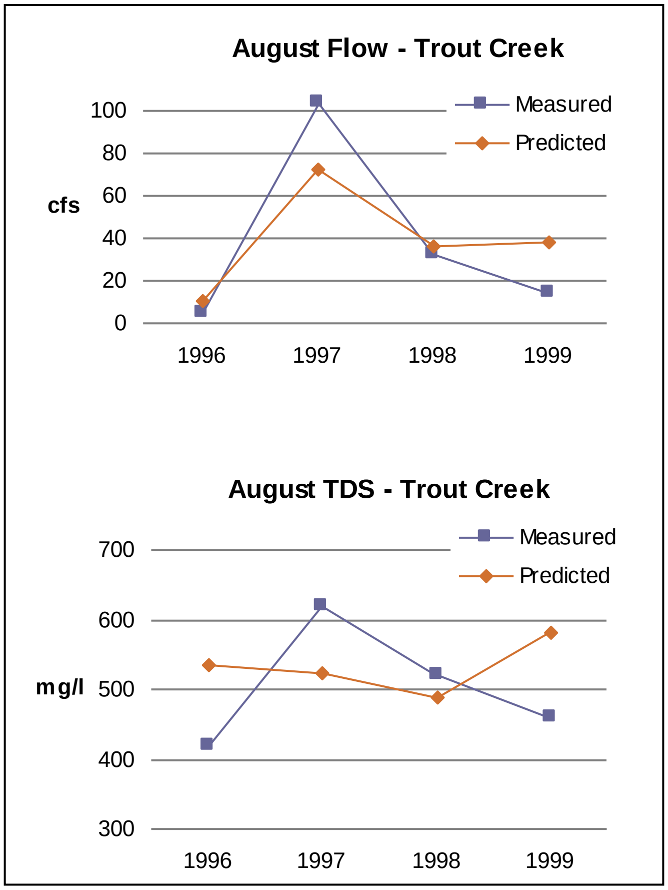


Figure 4 – Back-testing results for August on Trout Creek.

Minimum TDS concentrations on the mainstem occur in Scenario 1 (August, average yearly moisture, no pumping). In this scenario, TDS reaches only 248 mg/l at the node farthest downstream point (Node Y10). This TDS value is well below those predicted for all of the tributary streams where values commonly exceed 500 mg/l (Fig. 6). The large TDS loads in the tributaries apparently are diluted by the significantly larger flows of the mainstem (Fig. 7). Actual values could range from 50% to 100% of these predicted values, based on the amount of error found in back-testing (see previous discussion of back-testing).

Maximum TDS concentrations on the mainstem occur in Scenario 4 (August, dry moisture conditions, with mine pumping). In this scenario, pumping causes TDS to increase by 23%, compared to less than 10% in a year with average moisture conditions (Fig. 8). Actual percentages could range between one-half to twice these predicted percentages, based on the amount of error found in back-testing.

Table 3 - Predicted TDS concentrations (in mg/l) in the mainstem of the Yampa River mainstem for eight scenarios.

	Scenario:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Month:	August				April			
	Precipitation:	Average		Dry		Average		Dry	
	Pumping:	No	Yes	No	Yes	No	Yes	No	Yes
Point	**Mines on segment**								
Y3	Above all mining	135	135	125	125	147	147	149	149
Y4	Edna, Foidel Creek, part of Seneca II	190	205	205	241	223	228	198	199
Y5	All upstream mines, plus Yoast and Seneca II	192	208	212	248	227	232	203	204
Y6	All upstream mines, plus Yoast, Seneca II, and Seneca IIW	194	209	216	251	229	233	203	205
Y7	All upstream mines, plus HG Loadout, and part of Seneca IIW	194	210	217	253	230	235	203	206
Y8	All upstream mines, plus Trapper	196	212	221	257	231	235	204	207
Y9	All upstream mines, plus Eagle 5 & 9	230	253	239	308	285	291	247	253
Y10	All upstream mines, plus Colowyo	248	268	286	352	315	320	252	257

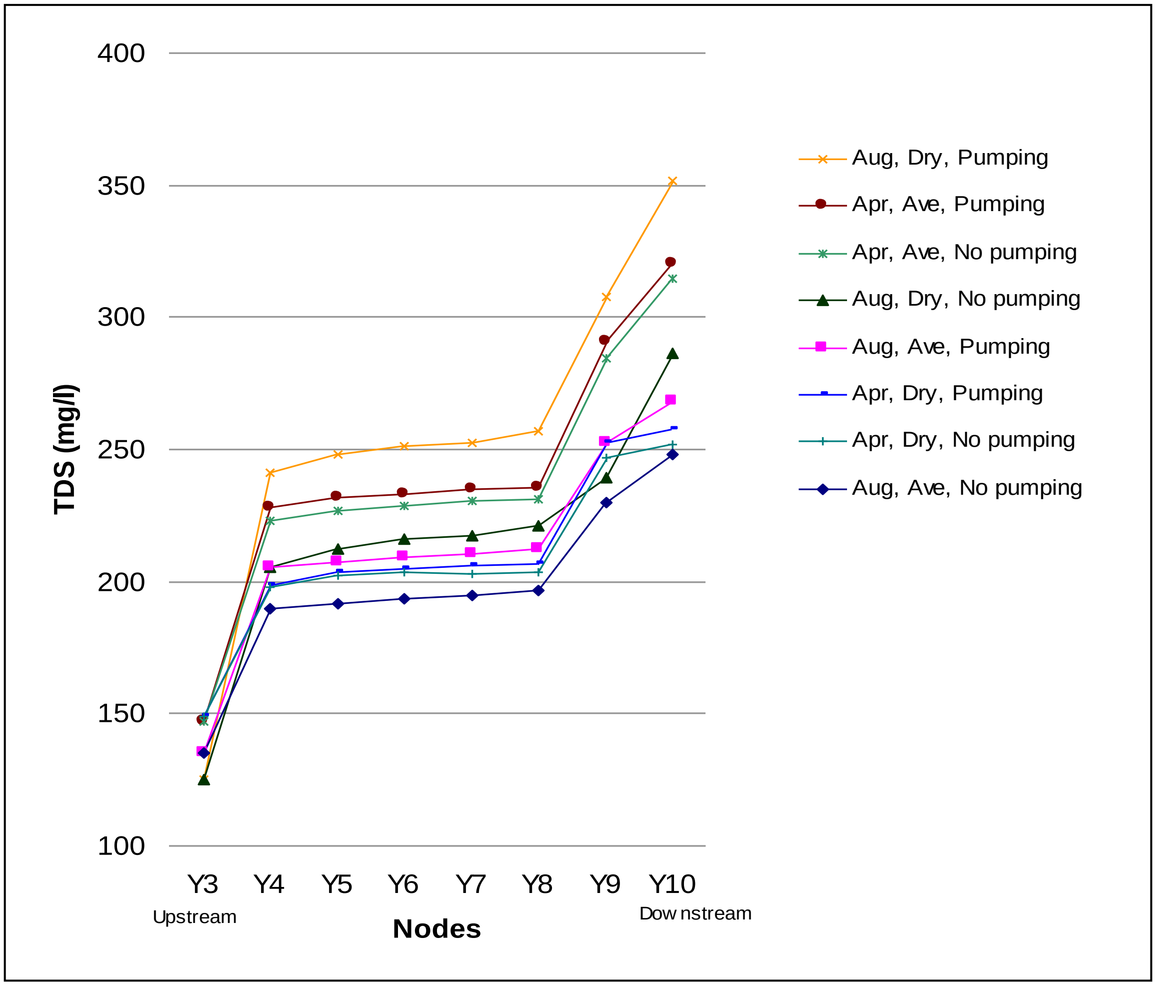


Figure 5 - Predicted TDS values at eight nodes on Yampa River Mainstem. Same data as shown in Table 3.)

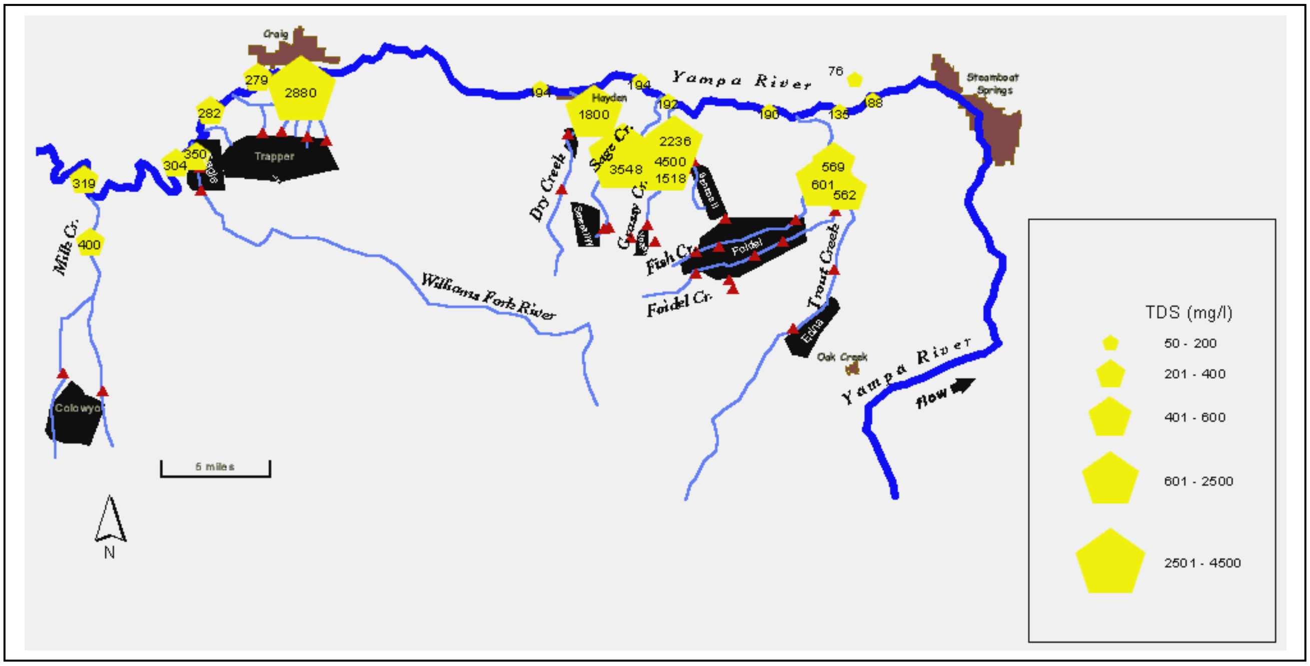


Figure 6 - Predicted TDS concentrations for Scenario 1 (August, average moisture conditions, no mine pumping).

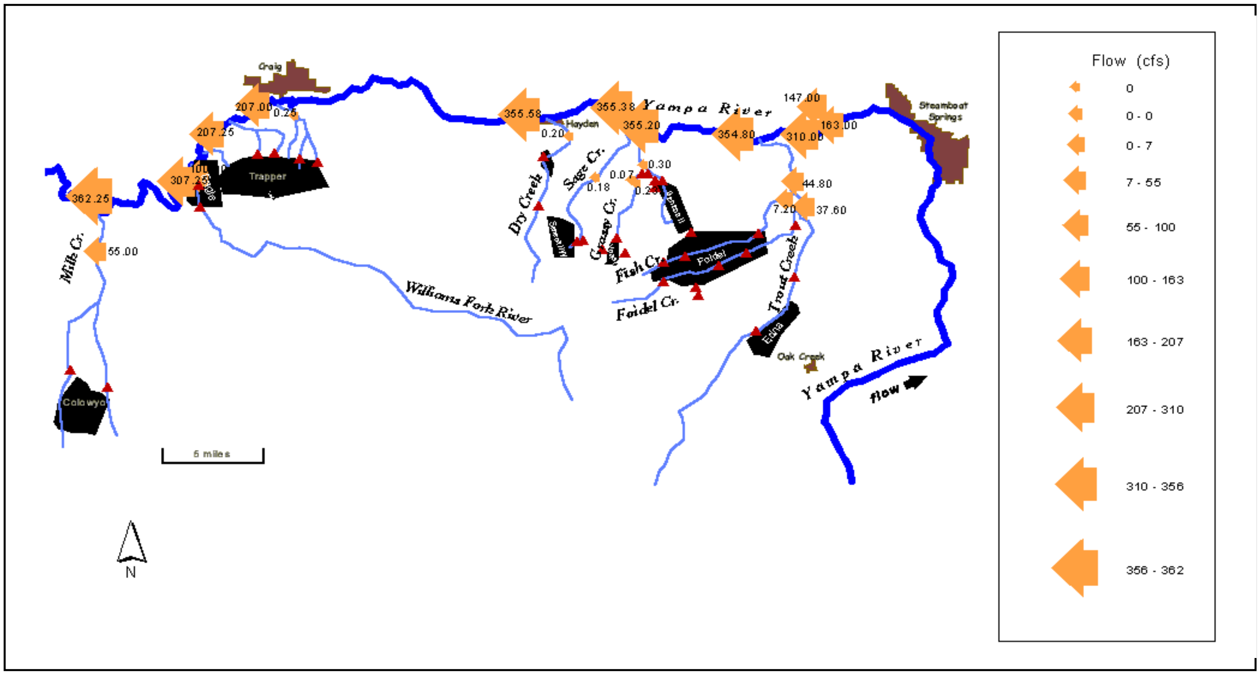


Figure 7 - Predicted flows for Scenario 1 (August, average moisture conditions, no mine pumping).

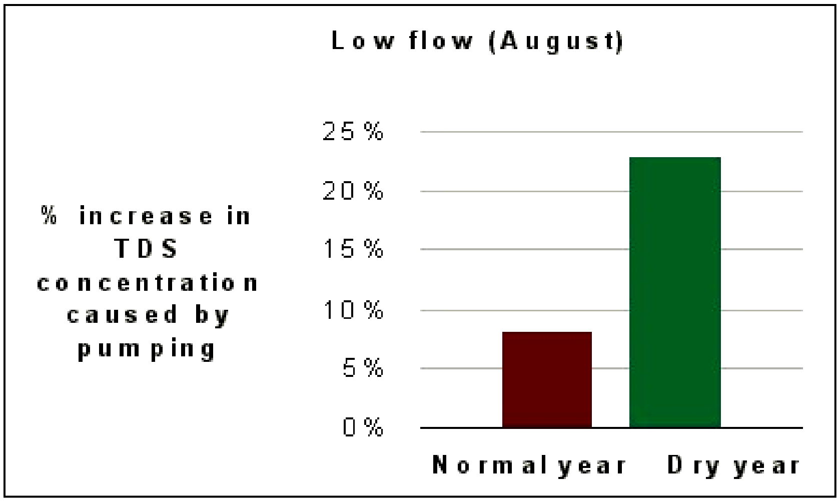


Figure 8 - Predicted increase in TDS concentration at Node Y10, the farthest downstream node, caused by mine pumping during late summer (low stream flows in August).

The effect of mine pumping is significantly reduced during high springtime flows in April, when pumping causes TDS to increase less than 4% (up to 8% with model error) in the mainstem of the Yampa River (Fig. 9). The dilution of streams is greatest during high springtime flows; consequently, most mine pumping is done during this period.

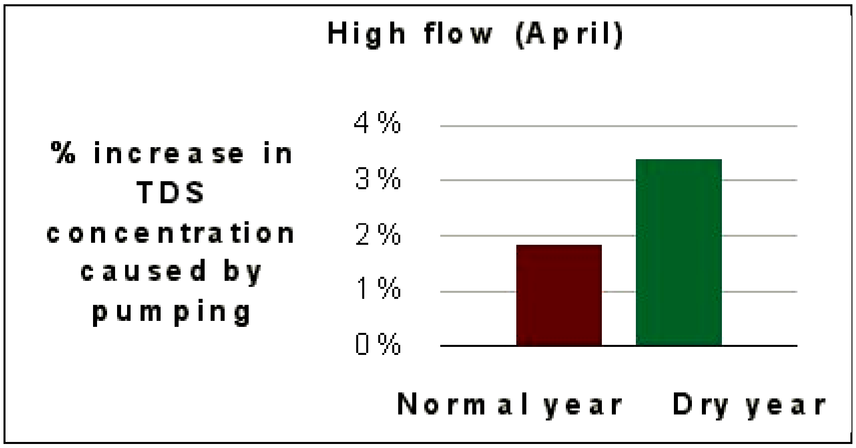


Figure 9 - Predicted increase in TDS concentration at Node Y10 (the farthest downstream node) caused by mine pumping during high springtime flow in April .

Conclusions

For TDS increases caused by mine pumping, the spreadsheets predict the greatest increases would occur in dry years. Of the eight scenarios considered in this study, the largest percentage increase in TDS would occur when there is uncontrolled mine pumping in a relatively dry year during low seasonal stream flow. In this worst-case scenario, the increase on the most affected stream segment could range between 12% and 46%. (In practice, mine pumping is controlled to prevent such an increase.) In a year of average precipitation, predicted TDS increases on the most affected stream segment would be up to 20% during low flows, and would be less than 8% during high seasonal stream flows. In some cases the spreadsheets appear to predict TDS within only about 50% of the actual value; therefore, it is important to recognize the the limitations of this method.

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