

# COMPARISON OF WATER QUALITY FOR UPSTREAM AND DOWNSTREAM SITES IN THE INCLINE CREEK WATERSHED, LAKE TAHOE BASIN, NEVADA, 1990-98

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## ABSTRACT

The U.S. Geological Survey, and the Tahoe Research Group, in cooperation with the Tahoe Regional Planning Agency, has monitored tributaries in the Lake Tahoe Basin since 1987. Monitoring is to determine streamflow and concentrations of sediment and nutrients to Lake Tahoe. In 1989, the monitoring network was expanded to support the assessment of the effects of land use and development on water quality in the basin. Data from one watershed, Incline Creek, are described for the 1990-98 water years.

The median values of instantaneous streamflow, specific conductance, suspended sediment, and bioreactive iron all increased in a downstream direction. Median streamflow increased from 3.1 to 8.2 ft<sup>3</sup>/s (cubic feet per second) and median specific conductance increased from 35 to 78  $\mu$ S/cm (microsiemens per centimeter) at 25°C (degrees Celsius). Also in a downstream direction, median suspended sediment increased from 7 to 24 mg/L (milligrams per liter) and median bioreactive iron increased from 242 to 972  $\mu$ g/L (micrograms per liter).

The median values of total Kjeldahl nitrogen and total phosphorus increased slightly in a downstream direction. Median total Kjeldahl nitrogen increased from 0.160 to 0.206 mg/L and median total phosphorus from 0.036 to 0.055 mg/L. The median values of water temperature, pH, and concentrations of dissolved oxygen, dissolved nitrite plus nitrate, dissolved ammonia, and dissolved orthophosphorus showed virtually no trends with distance downstream.

## INTRODUCTION

Lake Tahoe is an outstanding natural resource famous for its alpine setting and deep, clear water. Protection of Lake Tahoe has become very important in the past half century, as the clarity has been decreasing by about 1 ft/yr (foot per year; Goldman and Byron, 1986; Goldman and Reuter, 1997). This decrease is due mainly to human activities, which have increased dramatically in the Lake Tahoe Basin since 1960 (Byron and Goldman, 1989).

Increased nutrient concentrations within Lake Tahoe are considered the primary cause of increased algal growth and resultant loss of clarity in the lake. Suspended sediment also is of concern, because some nutrients, such as organic nitrogen and phosphorus, tend to attach to and thereby are available for transport with sediment particles. Tributary streamflow in the Lake Tahoe Basin is suspected of being one of the major pathways for nutrient and sediment transport to the lake. Increased development has accelerated this transport through urbanization of wetland areas and erosion from construction on moderate to steep slopes within the basin.






The Tahoe Regional Planning Agency (TRPA), the U.S. Geological Survey (USGS), the Tahoe Research Group of the University of California, Davis (TRG), and State and local agencies have been monitoring the Lake Tahoe Basin for nutrients and sediment since the 1970's. One cooperative program, a tributary-monitoring program by USGS and TRPA, began in 1988. All years referred to are water years—October 1 through September 30, and are designated by the year in which it ends. The primary purpose of this program is to provide a long-term data base for monitoring local water quality and for estimating the loads of nutrients and sediment from selected Lake Tahoe tributaries.

This program initially included 4 sites in 4 Lake Tahoe Basin watersheds and expanded to 13 sites in 7 watersheds in 1990. The purpose of expanding the data network was to support the assessment of the effects of land use and development in the Lake Tahoe Basin on water quality. The number of stations in the network was increased again in 1991 and 1992 to include 19 sampling sites in 7 watersheds for the purpose of providing additional water-quality information at possible problem locations. The current network includes 32 stream sampling sites, 20 with continuous streamflow gages, in 14 Lake Tahoe Basin watersheds where streamflow, sediment, and nutrient data are collected (Boughton and others, 1997).

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## DESCRIPTION OF STUDY AREA

**EXPLANATION**

	Incline Village developed area (Modified from Glancy, 1988)
<b>Selected tributaries of Incline Creek watershed</b>	
	Incline Creek above Tyrol (site 1)
	Incline Creek at Highway 28 (site 2)
	Incline Creek tributary (site 3)
	Incline Creek near Crystal Bay (site 4)

**2 Site and number**

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Incline Creek watershed (fig. 1), in the northeast part of the Lake Tahoe Basin, has a drainage area of 6.69 mi<sup>2</sup> (table 1) and drainage perimeter of 11.8 mi (Cartier and others, 1995). Incline Creek channel altitude ranges from 6,225 ft at lake level to 8,420 ft, and the maximum watershed altitude at 9,225 ft (Jorgensen and others, 1978). The average main-channel gradient is 540 ft/mi (feet per mile; Glancy, 1988) with a total channel length of 4.7 mi (Jorgensen and others, 1978). The watershed is mountainous, with 36% (percent) above 8,000 ft altitude, 43% between 7,000 ft and 8,000 ft, and 21% below 7,000 ft (Glancy, 1988).

**Table 1.** Selected characteristics of four sites in Incline Creek study area for 1990–98 water years

[Symbol: --, data not available]

Characteristic	Incline Creek above Tyrol, site 1	Incline Creek at Highway 28, site 2	Incline Creek tributary, site 3	Incline Creek nr Crystal Bay, site 4
USGS station number	103366993	103366995	103366997	10336700
Data collected	Continuous streamflow, instantaneous nutrients, sediment	Continuous streamflow, instantaneous nutrients, sediment	Instantaneous streamflow, nutrients, sediment	Continuous streamflow, instantaneous nutrients, sediment
Period of record, water years	1990-98	1990-98	1991-98	1990-98
Drainage area, square miles (Cartier and others, 1995)	2.85	4.54	1.50	6.69
Altitude, feet (Cartier and other, 1995)	6,920	6,320	6,760	6,247
Distance from Lake Tahoe, mile	2.5	0.6	2.0	0.2
Instantaneous peak recorded streamflow, cubic feet per second	52	143	--	164
Mean annual streamflow, cubic feet per second	4.65	6.52	--	8.59
Average annual runoff, acre-feet	3,370	4,730	--	6,230

The upstream site, Incline Creek above Tyrol (site 1, fig. 1), is about 2.5 mi from Lake Tahoe, at an altitude of 6,920 ft, and has drainage area of 2.85 mi<sup>2</sup> (table 1; Cartier and others, 1995) that is undeveloped. The middle site, Incline Creek at Hwy. 28 (site 2), is about 0.6 mi from the lake, at an altitude of 6,320 ft, and has a drainage area of 4.54 mi<sup>2</sup>. About 30% of the area upstream from site 2 has been developed for residential and recreational use (ski area and part of a golf course). Incline Creek tributary (site 3) is about 2.0 mi from the lake, at an altitude of 6,760 ft, and has a drainage area of approximately 1.5 mi<sup>2</sup>, consisting of about 40% residential area, 60% undeveloped area, and a major highway crossing (Hwy. 431). The Incline Creek tributary enters Incline Creek about 500 ft below site 2. The near-mouth site, Incline Creek near Crystal Bay (site 4), is about 0.2 mi from the lake, at an altitude of 6,247 ft, and has a drainage area of 6.69 mi<sup>2</sup>. Approximately 40% of the drainage upstream from site 4 had been developed for commercial, residential, and recreational uses and 60% of the area remains undeveloped (Glancy, 1988).

Precipitation, which falls mostly as snow from November into June, ranges from 30 to 35 in/yr (inches per year; Crippen and Pavelka, 1970). Other precipitation periods include periodic autumn rains and summer thunderstorms. Annual precipitation in the watershed was below normal for 4 years (1990–92 and 1994) and above normal for the remaining 5 years (1993, 1995–98) of the data-collection period (Dan Greenlee, Natural Resources Conservation Service, oral communication, 1999).

Geologically, the watershed consists mainly of granitic and volcanic rocks and basin-fill deposits (Burnett, 1971). Site 3 is notably different from the main channel sites as its tributary area is underlain mainly by volcanic rocks and basin-fill deposits. Vegetation predominant in the area includes coniferous forest, riparian, and brushland, interspersed with some urban development and barren areas. Development is mainly limited to relatively flat areas along the lake, creeks, and the initial mountain slope, because most of the watershed is mountainous and too steep for development. The largest amount of development in the Incline Creek watershed occurred from 1960 to 1970 (Glancy, 1988).

## **METHODS**

Incline Creek was partitioned into four sub-drainage areas. The upstream main channel site (site 1) was located above known development. The middle site (site 2) was located in the developed area, with approximately 30% of the upstream area developed. The lowest site (site 4) was located near the mouth to include almost all the development (40%) in the watershed. The tributary site (site 3) was chosen because it was thought to contribute significant concentrations of sediment to Incline Creek.

Streamflow was measured or values obtained from the gaging stations using the current stage-discharge relationship. Streamflow was measured and gaging stations operated according to USGS guidelines (Buchanan and Somers, 1969; Kennedy, 1983). All streamflow data are available in USGS electronic data bases and annual data reports.

Water-quality samples were collected using USGS guidelines (Edwards and Glysson, 1988). The samples were analyzed for nutrients and iron by the TRG laboratories in Davis and Tahoe City, Calif., according to procedures described by Hunter and others (1993). The samples were analyzed for suspended sediment by the USGS sediment laboratory in Salinas, Calif., using USGS guidelines (Guy, 1969). All water-quality data are available in USGS data bases and published in annual data reports (U.S. Geological Survey, 1991–99). Samples at the three main-channel sites (sites 1, 2, and 4) were collected on a routine monthly basis during low-flow periods. Water was then sampled more frequently, at all hours of the day, during autumn rain, rain-on-snow, spring snow-melt runoff, and summer thunderstorm runoff, and during low-flow periods, in the 1990–98 water years. Samples at the tributary site (site 3) were collected in the 1991–98 water years at a much less frequent rate and not during low-flow periods.

For each of the four sampling sites, summary statistics were calculated for instantaneous field measurements of streamflow, water temperature, specific conductance, pH, and dissolved oxygen and laboratory determined concentrations of suspended sediment and six nutrients were made using methods described by Helsel and Hirsch (1992). These statistics are shown in table 2. Median values were chosen for the calculations because they are not strongly influenced by extreme values. The comparison among the upstream and downstream sites is done for the three main-channel sites (sites 1, 2, and 4), and the tributary site (site 3) statistics are listed for information.

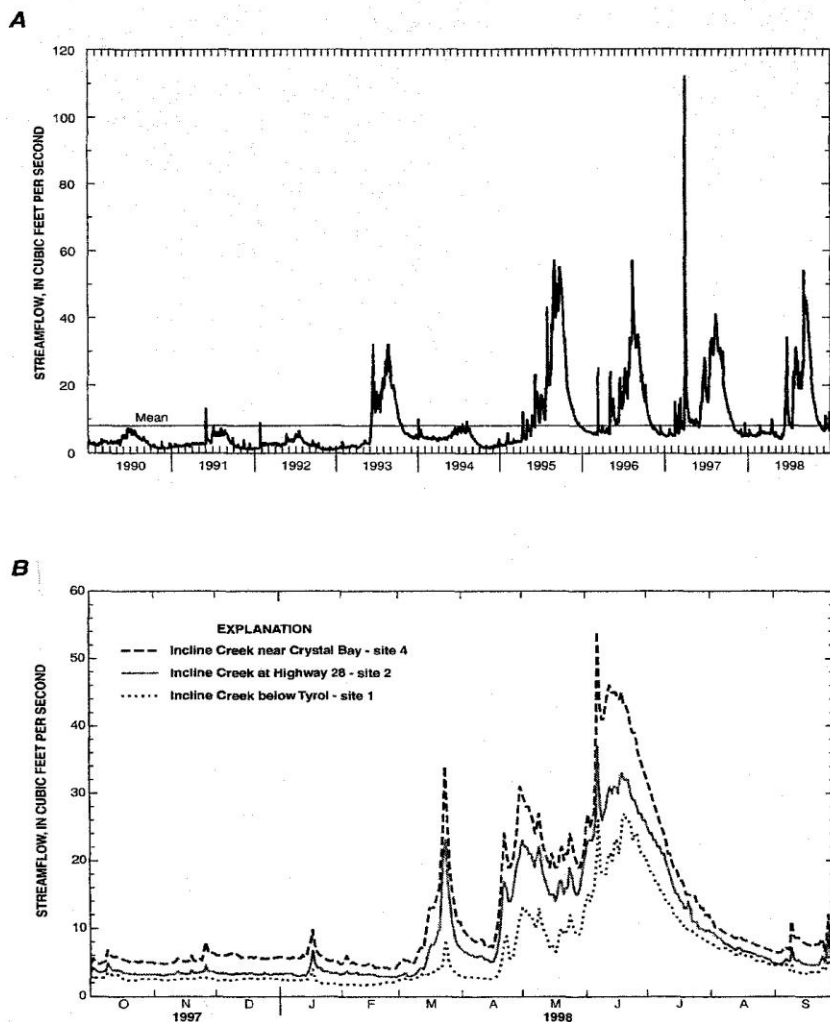
## **RESULTS**

The streamflow hydrograph for the entire 9-year study period at site 4 illustrates the drought and above-normal precipitation periods (fig. 2A). The annual runoff pattern, as illustrated by the 1998 water-year hydrograph (fig. 2B), is typical for the Lake Tahoe Basin, with most of the flows occurring during snow-melt runoff with other peaks during autumn rains, rain-on-snow, and summer thunderstorms. For the study period, the peak streamflow from continuous recorders all occurred during the flood of January 1997 and were 52 ft<sup>3</sup>/s at site 1, 143 ft<sup>3</sup>/s at site 2, and 164 ft<sup>3</sup>/s at site 4. The mean annual streamflow for the 1990–98 water years for sites 1, 2, and 4 was 4.65, 6.52, and 8.59 ft<sup>3</sup>/s, respectively. Average annual runoff for sites 1, 2, and 4 was 3,370, 4,730, and 6,230 acre/ft (acre-feet), respectively.

Median values for instantaneous streamflow at sites 1–4 (fig. 3; table 2), determined during sample collection, were 3.1 ft<sup>3</sup>/s with 314 values, 4.7 ft<sup>3</sup>/s, with 294 values, 2.9 ft<sup>3</sup>/s with only 85 values, and 8.2 ft<sup>3</sup>/s with 397 values, respectively (fig. 3A). The highest instantaneous sampled streamflow was 161 ft<sup>3</sup>/s, at site 4 during the flood of January 1997.

Median values for specific conductance were 35 µS/cm at site 1, 51 µS/cm at site 2, 144 µS/cm at site 3, and 78 µS/cm at site 4 (fig. 3B; table 2). The highest instantaneous specific conductance measured for the three main-channel sites was 166 µS/cm at site 4 during early snow-melt runoff in February 1992. Site 3 had consistently higher specific-conductance values than the other three Incline Creek sites and had the highest value measured at 210 µS/cm during a rain-on-snow sample in January 1998. The lowest specific-conductance value measured for all four sites was 19 µS/cm at site 1 during spring snow-melt runoff.

Median instantaneous suspended-sediment concentrations were 7 mg/L at site 1, 16 mg/L at site 2, 14 mg/L for site 3, and 24 mg/L at site 4 (fig. 3C). The highest suspended-sediment value measured was 1,840 mg/L, at site 4 (table 2) during rain-on-snow runoff in April 1991. Many times the lowest suspended-sediment value measured was 1 mg/L at sites 1, 2, and 4 during low-flow periods.



**Figure 2.** Daily mean streamflow for (A) Incline Creek near Crystal Bay (site 4) 1990-98 water years; (B) Incline Creek gaged sites, 1998 water year.

Median values for instantaneous total bioreactive iron (TFe) were 242  $\mu\text{g/L}$  at site 1, 824  $\mu\text{g/L}$  at site 2, 564  $\mu\text{g/L}$  at site 3, and 972  $\mu\text{g/L}$  at site 4 (fig. 3D; table 2). The highest instantaneous iron value measured was 28,500  $\mu\text{g/L}$ , at site 4 during rain-on-snow runoff in March 1995. The lowest instantaneous iron value measured was 66.6  $\mu\text{g/L}$ , at site 1 during a low-flow period.

Median instantaneous concentrations for the nutrient determinations, total Kjeldahl (ammonia + organic) nitrogen (TKN) (fig. 4A) and total phosphorus (TP) (fig. 4B), were determined from unfiltered samples. Median values for instantaneous TKN were 0.160 mg/L at site 1, 0.171 mg/L at site 2, 0.166 mg/L at site 3, and 0.206 mg/L at site 4 (fig. 4A; table 2). The highest instantaneous TKN value measured was 2.97 mg/L, at site 4 during rain-on-snow runoff in March 1991. The lowest instantaneous TKN value measured was 0.009 mg/L, at site 4 during a low-flow period. Median values for instantaneous TP were 0.036 mg/L at site 1, 0.050 mg/L at site 2, 0.055 mg/L at site 4, and 0.046 mg/L at site 3 (fig. 4B; table 2). The highest instantaneous TP value measured was 1.19 mg/L, at site 4 during the flood in January 1997. The lowest instantaneous TP value measured was 0.004 mg/L, at site 4 during a low-flow period.

**Table 2.** Instantaneous streamflow and water-quality variable ranges and medians for four sites in the Incline Creek study area for 1990–98 water years

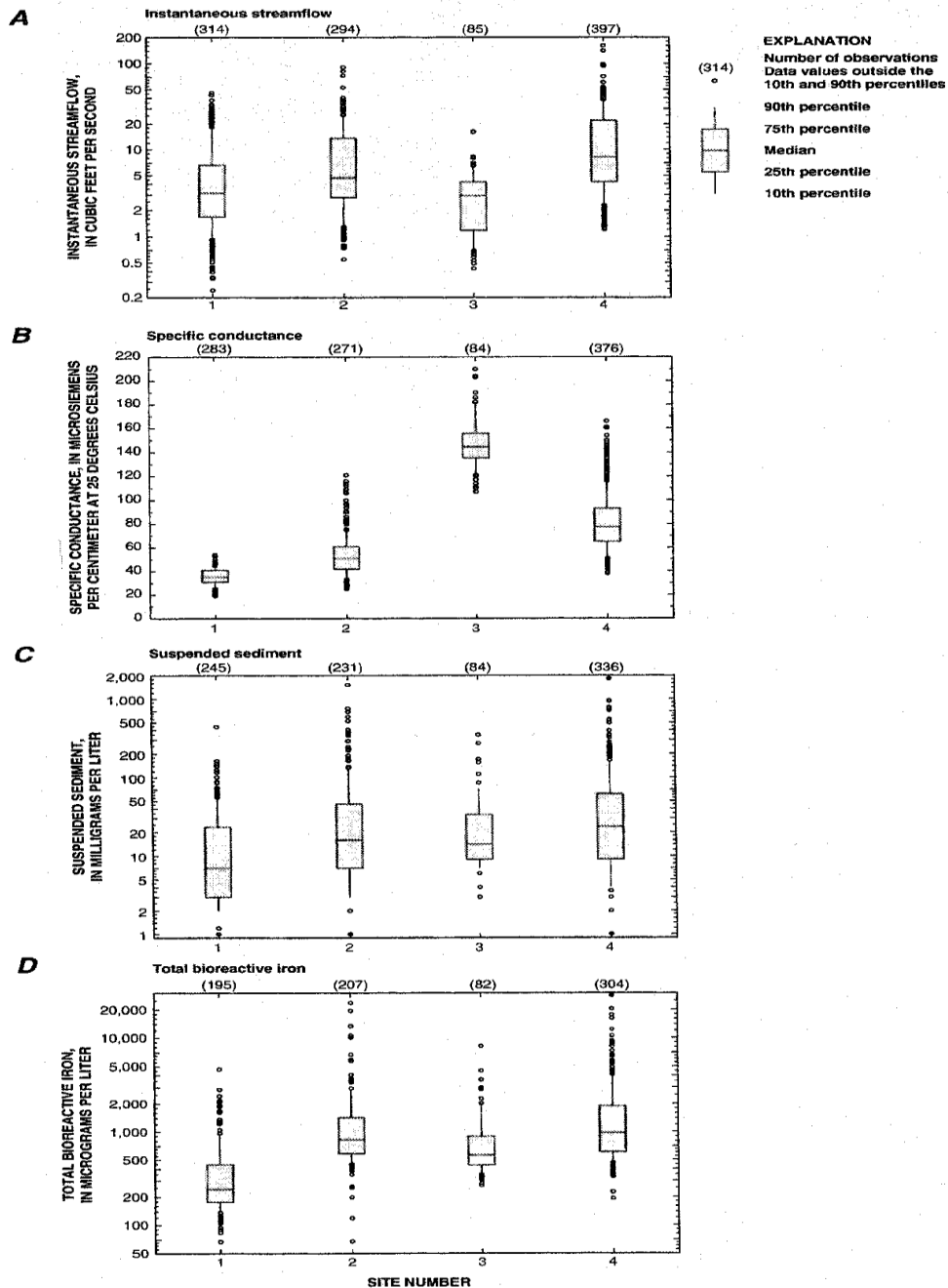
[Abbreviations: ft<sup>3</sup>/s, cubic feet per second; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. **Bold** value indicates maximum value and maximum median value among all sites]

Instantaneous measurement	Incline Creek above Tyrol, site 1	Incline Creek at Highway 28, site 2	Incline Creek tributary, site 3	Incline Creek nr Crystal Bay, site 4
Streamflow, ft <sup>3</sup> /s	range = 0.24 - 46 median = (3.1)	0.55 - 91 (4.7)	0.43 - 16.2 (2.9)	1.2 - <b>161</b> ( <b>8.2</b> )
Water temperature, °C	0.0 - <b>18.0</b> (5.0)	0.0 - 14.5 (6.0)	1.5 - 14.5 ( <b>8.4</b> )	0.0 - 15.5 (6.0)
Specific conductance, µS/cm	19 - 54 (35)	25 - 121 (51)	107 - <b>210</b> ( <b>144</b> )	38 - 166 (78)
pH, units	7.1 - <b>8.6</b> (7.8)	6.9 - 8.5 (7.8)	7.5 - 8.3 ( <b>8.0</b> )	7.0 - <b>8.6</b> (7.9)
Dissolved oxygen, mg/L	7.2-12.1 ( <b>9.8</b> )	7.8-11.8 (9.7)	7.9-10.4 (9.3)	7.9- <b>12.5</b> (9.7)
Dissolved oxygen, percent saturation	87-115 ( <b>100</b> )	93-108 (99)	94-113 (99)	94- <b>116</b> ( <b>100</b> )
Suspended sediment, mg/L	1 - 443 (7)	1 - 1,530 (16)	3.0 - 348 (14)	1 - <b>1,840</b> ( <b>24</b> )
Total bioreactive iron (Tfe), µg/L	66.6 - 4,700 (242)	67.3 - 23,700 (824)	267 - 8,170 (564)	193 - <b>28,500</b> ( <b>972</b> )
Total Kjeldahl (TKN, ammonia+organic) N, mg/L	0.034 - 2.96 (0.160)	0.022-1.67 (0.171)	0.054 - 1.29 (0.166)	0.009 - <b>2.97</b> ( <b>0.206</b> )
Total phosphorus (TP), mg/L	0.010 - 0.368 (0.036)	0.007 - 1.02 (0.050)	0.024 - 0.361 (0.046)	0.004 - <b>1.19</b> ( <b>0.055</b> )
Dissolved ammonia nitrogen (DNH <sub>4</sub> ), mg/L	<0.001 - <b>0.055</b> (0.001)	<0.001 - 0.052 ( <b>0.002</b> )	<0.001 - 0.015 (0.001)	<0.001 - 0.030 ( <b>0.002</b> )
Dissolved nitrate+nitrite (DNO <sub>2</sub> + NO <sub>3</sub> ), mg/L	0.002 - 0.101 (0.021)	0.003 - 0.082 (0.025)	0.014 - <b>0.151</b> ( <b>0.046</b> )	0.003 - 0.094 (0.029)
Dissolved orthophosphorus (DOP), mg/L	<0.001 - <b>0.086</b> (0.011)	0.003 - 0.074 ( <b>0.012</b> )	0.003 - 0.025 (0.009)	0.003 - 0.073 (0.011)

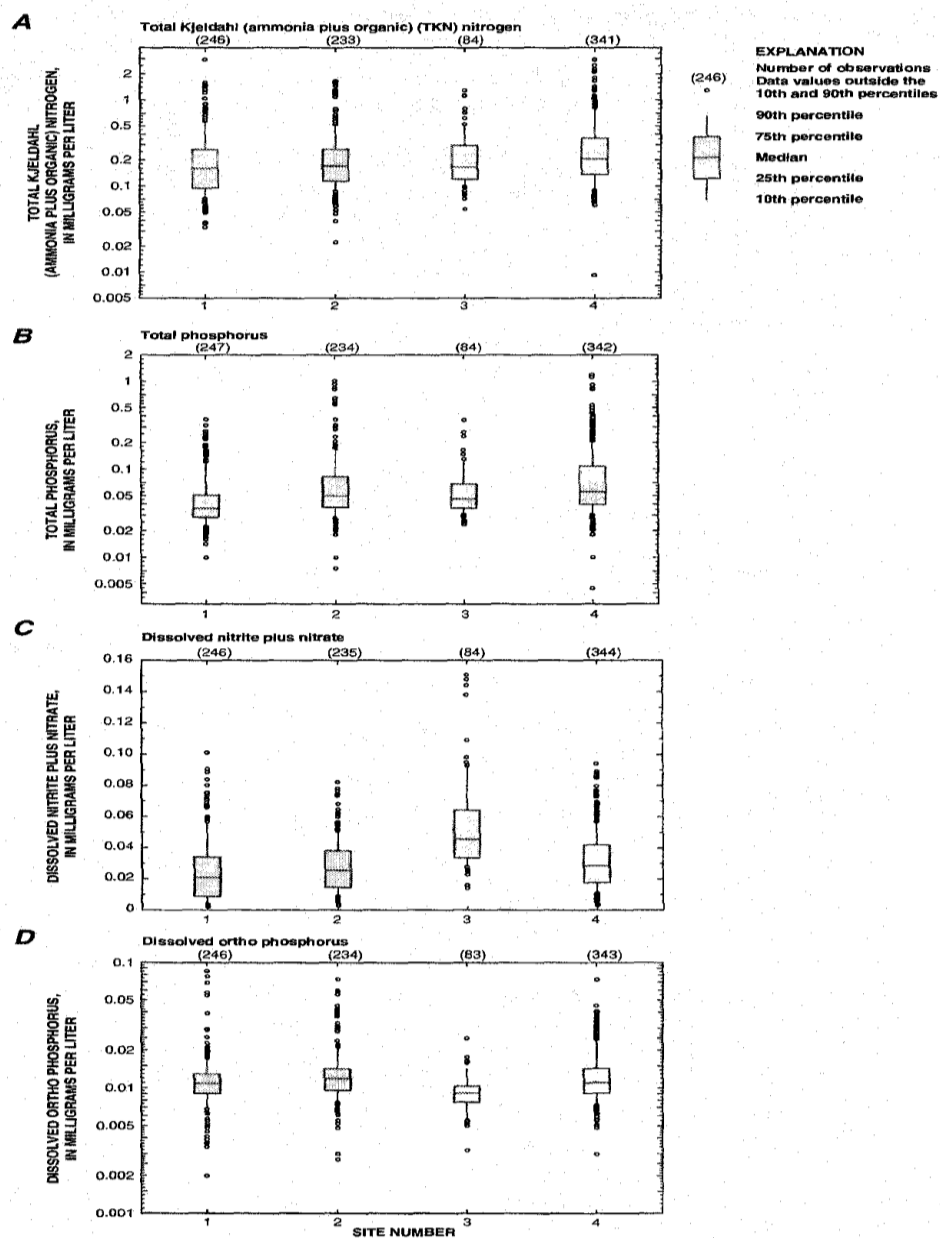
Median instantaneous concentrations of three nutrient determinations, dissolved nitrite plus nitrate (DNO<sub>2</sub> + NO<sub>3</sub>), dissolved ammonia (DNH<sub>4</sub>), and dissolved orthophosphorus (DOP), were determined from filtered samples. Median values for instantaneous DNO<sub>2</sub> + NO<sub>3</sub> were 0.021 mg/L at site 1, 0.025 mg/L at site 2, 0.046 mg/L at site 3, and 0.029 mg/L at site 4 (fig. 4C; table 2). The highest instantaneous DNO<sub>2</sub> + NO<sub>3</sub> value measured was 0.151 mg/L, at site 3 during rain-on-snow runoff in April 1991, and the lowest instantaneous DNO<sub>2</sub> + NO<sub>3</sub> value measured was 0.002 mg/L, at site 1 during low-flow periods. Site 3 had higher instantaneous DNO<sub>2</sub> + NO<sub>3</sub> readings for the most part than the three main-channel Incline Creek sites.

Median instantaneous concentrations values for DNH<sub>4</sub> were 0.001 mg/L at site 1, 0.002 mg/L at site 2, 0.001 mg/L at site 3, and 0.002 mg/L at site 4. The highest instantaneous DNH<sub>4</sub> value measured was 0.055 mg/L, at site 1 during summer thunderstorm runoff in September 1994, and the lowest value was <0.001 mg/L, at all four sites during low-flow periods. Median values for instantaneous DOP were 0.011 mg/L at site 1, 0.012 mg/L at site 2, 0.009 mg/L at site 3, and 0.011 mg/L at site 4 (fig. 4D; table 2). The highest instantaneous DOP value measured was 0.086 mg/L, at site 1 during summer thunderstorm runoff in September 1994, and the lowest DOP value measured was <0.001 mg/L, at site 1 during low-flow periods.

Median instantaneous values for water temperature were 5.0°C (degrees Celsius) at site 1, 6.0°C at site 2, 8.5°C at site 3, and 6.0°C at site 4. The highest instantaneous water temperature measured was 18.0°C, at site 1 during the summer months. The lowest value measured was 0.0°C, at sites 1, 2, and 4 during the winter months (November to April).



**Figure 3.** Boxplots showing statistical summaries of (A) instantaneous streamflow; (B) specific conductance; (C) suspended-sediment concentrations; and (D) total bioreactive-iron concentrations for Incline Creek sites, 1990-98 water years.



**Figure 4.** Boxplots showing statistical summaries of (A) instantaneous total Kjeldahl (ammonia + organic) nitrogen (TKN) concentrations; (B) total phosphorous concentrations; (C) dissolved nitrite + nitrate concentrations; and (D) dissolved orthophosphorus concentrations for Incline Creek sites, 1990-98 water years.



Median instantaneous values for pH were 7.8 at site 1, 7.8 at site 2, 8.0 at site 3, and 7.9 at site 4. The highest instantaneous pH measured reading was 8.6 at sites 1 and 4 during winter periods. The lowest instantaneous pH value measured was 6.9 at site 2 during April 1995.

Median instantaneous values for dissolved oxygen (DO) were 9.8 mg/L at site 1, 9.7 mg/L at site 2, 9.3 mg/L at site 3, and 9.7 mg/L at site 4. The highest instantaneous DO value measured was 12.5 mg/L, at site 4 during winter months. The lowest instantaneous DO value measured was 7.2 mg/L, at site 1 during summer months. Median values of DO percent saturation were 100% at site 1, 99% at site 2, 100% at site 4, and 99% at site 3. The highest instantaneous DO percent saturation measured was 116% at site 4 during winter months. The lowest value measured was 87% at site 1 during summer months.

### **SUMMARY AND CONCLUSIONS**

Comparisons among sites in developed and undeveloped areas can only be broad and general, due to limited concurrent data. Water samples could not always be collected at the three main channel, sites 1, 2 and 4, and one tributary site (site 3) in Incline Creek watershed at the same time of day or at the same point on the flow hydrograph, or during the same event, due to staffing and time limitations. Data on the tributary site are limited.

Median values for specific conductance increased approximately 200% going downstream from the undeveloped area through various levels of development. The increase in specific conductance probably is due to increased contribution of ground water, increased salts from lawn runoff and increased runoff from the network of roads in the developed area. The high levels of specific conductance at site 3 probably are due to increased contributions of ground water and differing geology from that of the main channel sites. Road runoff, which includes road salt and sand, is highest during the early snow-melt runoff flushes in the spring.

Median values for suspended-sediment and iron concentrations showed an increase of about 300% going from the undeveloped area down through various levels of development. This increase may be due to actual direct runoff from various land-use practices, increased erosion due to road runoff, and increased channel erosion. Higher suspended-sediment concentrations during rain on snow may be, in part, due to snow removal practices of pushing road/parking lot snow into stream areas. Increased channel erosion may be caused by faster flow velocities brought on by activities that include stream channelization/straightening and the reduction of small wetland areas that existed prior to development. Impervious land coverage (for example, building roofs and paved parking lots) also may deliver more runoff to the streams at a faster rate.

Median values for the two total nutrient determinations, TKN and TP, showed an increase of only about 25–50% in concentration from upstream to downstream sites. Median concentrations for the three dissolved-nutrient determinations,  $\text{DNO}_2 + \text{NO}_3$ ,  $\text{DNH}_4$ , and DOP showed virtually no along-stream trends. One possible reason for the increase in total nutrients and iron is that they can attach onto sediment particles which increase in number in a downstream direction. The dissolved nutrients tend not to attach onto the sediment particles and concentrations therefore remain unchanged by the increased quantity of sediment.

Median values for water temperature, pH, and DO showed virtually no along-stream trends during 1990-98 water years, indicating fairly stable conditions between sites.

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