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Impacts of Gold Mining and Land Use Alterations on the Water Quality of Central Mongolian Rivers

Andrew Stubblefield,† Sudeep Chandra,‡ Sean Eagan,§ Dampil Tuvshinjargal,|| Gantimur Davaadorzh,|| David Gilroy,# Jennifer Sampson,†† Jim Thorne,‡‡ Brant Allen,§§ and Zeb Hogan#*

†Department of Geological Sciences, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, Ohio 44106, USA
‡Department of Natural Resources and Environmental Sciences, University of Nevada, Reno, Mail stop 186, 1000 Valley Road, Reno, Nevada 89512, USA
§Sierra Nevada Research Center, Pacific Southwest Forest Service, U.S. Department of Agriculture, 2081 E. Sierra Avenue, Fresno, California 93710
||Institute of Geography, MAS, University of Mongolia, Ulaanbaatar, Mongolia UB-210620
#Center for Limnology, University of Wisconsin–Madison, 680 North Park Street, Madison, Wisconsin 53706, USA
††10,000 Years Institute, PO Box 11723, Bainbridge Island, Washington 98110, USA
§§Information Center for the Environment, Wickson Hall, University of California–Davis, Davis, California 95616, USA
‡‡Tahoe Research Group, Department of Environmental Science and Policy, University of California–Davis, Davis, California 95616, USA

Original Research

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ABSTRACT

Conservation of water quality is inherently tied to watershed management. Efforts to protect Lake Baikal have increasingly focused on the Selenge River, a major tributary, with more than half its watershed area in Mongolia. Placer gold mining in Mongolia has the potential to load total suspended sediment (TSS), and total phosphorus (TP) into Lake Baikal and destroy spawning areas for the endangered Taimen salmon (*Hucho taimen taimen*). This work describes water quality assessments performed from 2001 to 2003 on Mongolian tributaries to the Selenge River. Of 7 rivers sampled, rivers with proximal mining had the worst water quality. Elevated loading of TSS and TP was observed below mining regions on the Tuul River. Flooding could breach thin strips of land separating dredge pits from river channels, resulting in massive sediment loading. Extensive disturbance of the river terrace was apparent for many square kilometers. In the mountainous headwaters of the Yeroo River, tributary drainages undergoing mining had TP concentrations 8 to 15 times higher than the main stem. TSS was 7 to 12 times higher, and turbidity was 8 times higher. Alternative mining technologies exist that could minimize impact and improve the possibility for reclamation.

Keywords: Phosphorus Suspended sediment Lake Baikal Mining Mongolia

INTRODUCTION

The Selenge River is the largest single inflow to Lake Baikal and is a major factor influencing the water quality of the lake (Garmaeva 2001). Of the total watershed area for the Selenge River Basin (447,000 km^2), 66% is within Mongolia (Figure 1). Recent and accelerating placer gold mining activity within the floodplains of Mongolian rivers has been observed to introduce large quantities of fine sediment into the water (Dallas 1999; see also Farrington 2000). This sediment poses a potential threat to the water quality of Lake Baikal and to the spawning gravels of the Siberian Taimen (*Hucho taimen taimen)*, the world's largest salmon (Matveyev et al. 1998*)*, and the endangered Baikal Sturgeon (*Acipenser baerii baicalensis*) (Baasanjav and Tsend-Agush 2001).

Although extensive research has been conducted on the water quality of Lake Baikal (Galaziy 1980; Plumley 1997; Yoshioka et al. 2002) and on the Russian reaches of the Selenge (Munguntsetseg 1984; Ubuganov et al. 1998; Dambiev and Mairanovsky 2001; Garmaeva 2001; Korytny et al. 2003; Khazheeva et al. 2004), limited information is available on the conditions of Mongolian rivers (Batima and Davaa 1994; Batima 1998; Dallas 1999).

* To whom correspondence may be addressed andrew.stubblefield@case.edu

The Mongolian portion of the Selenge River watershed is composed predominantly of broad alluvial valleys flowing through steppe grasslands with source areas in taiga and mountain ecosystems. Maximum river discharge is driven by the spring melt of the accumulated snowpack. A 2nd peak in river hydrographs is observed in late summer, August or September, during the rainy season (Mongolian Institute for Meteorology and Hydrology, unpublished data) (Table 1). The principal land use is grazing. Other land uses include mining, forestry, and row crop agriculture.

Previous research indicated the loss of floodplain habitat and grazing lands, the introduction of large quantities of suspended sediment to the Tuul River for tens of kilometers, and a potential threat to habitat for taimen, grayling (*Thymallus arcticus arcticus)*, lenok (*Brachymystax lenok)*, burbot (*Lota lota)*, Siberian roach (*Rutilus rutilus)*, and the endangered Baikal sturgeon (Matveyev et al. 1998; Baasanjav and Tsend-Agush 2001). These losses and threats are predominantly thought to be the result of the inefficient and noncontemporary mining methods used by mining companies in the region (Dallas 1999; see also Bazuin 2003).

Gold placer mining is generally practiced using draglines from gold mining placer dredges to remove topsoil, vegetation, and up to 10 m of overlying layers of alluvium. Gold is sifted out of the gravel by a massive tumbler inside the dredge, and the resulting gravel is deposited behind the dredge. More than 4,000 m^3 of gravel and sand is processed in

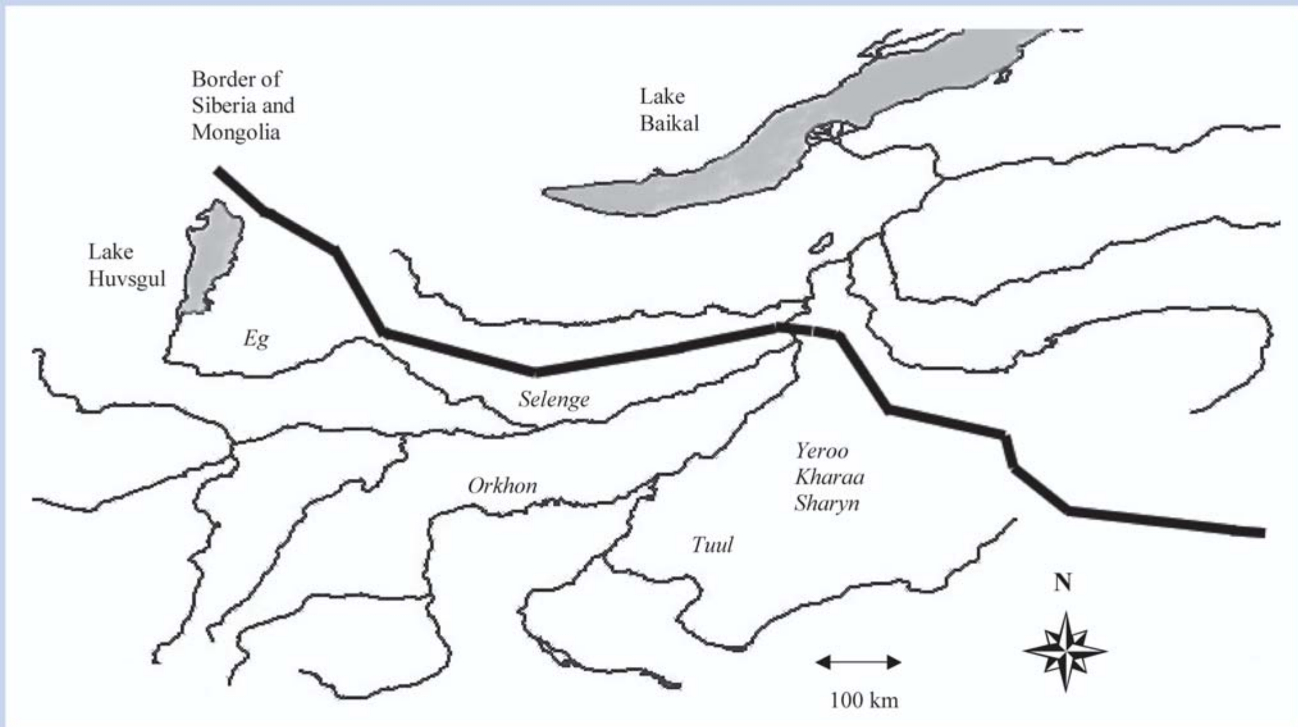

Figure 1. Overview of study area: Mongolian portion of the Selenge River watershed of Lake Baikal. Thick line indicates border between Mongolia and Siberia. Thinner lines show the Selenge River and major tributary drainages.

a day (Shijir-Alt Ltd., staff geologist, personal communication). A single dredge can cover several kilometers of floodplain in a year, yielding approximately 1 metric ton of gold. Mining operations take place in dredge pits next to the river. Only a narrow spit of land is typically left between the dredge pit and the river. During flooding events, there is a strong potential for the river to erode away the spit releasing highly turbid dredge pit water.

In the absence of routine water quality monitoring in this remote region, the central objective of this research was to conduct a broad water quality assessment of the major tributary rivers flowing into the Selenge River, emphasizing the areas with extensive gold mining activity. Specific water quality parameters measured include total phosphorus (TP), total suspended sediment, dissolved oxygen, turbidity, salinity, and discharge. These measurements were chosen as important indicators of water quality and sediment loading (Wetzel 1983). This assessment of current water quality will serve as a baseline for future monitoring efforts, against which the effects of land use changes will be measured.

Table 1. Comparison of maximum river flows in the Mongolian portion of the Selenge River watershed using historical flow data from the former Soviet Union era[a]

Location of units	Watershed area (km^2)	Period of record (y)	August mean ($m^3 \cdot s^{-1}$)	7–12 August 2001 ($m^3 \cdot s^{-1}$)	18–21 August 2001 ($m^3 \cdot s^{-1}$)
Selenge River at Ingettolgoi Station	139,000	1957–1969	595	540	577
Eg River at Khantai (village)	41,500	1959–1969	256		
Orkhon River at Orkhon (village)	23,600	1945–1969	123	25	27
Orkhon River at Sukbaatar (town)	132,000	1950–1958	222	70	125
Tuul River at Ulaanbaatar (city)	6,300	1947–1969	71.8	11	15
Kharaa River at Baruunkharaa station	9,580	1951–1969	23.1	5	7
Yeroo River at Yeroo (village)	8,975	1959–1969	150	26	51

[a] Data courtesy of Mongolian Ministry of Meteorology and Hydrology.

METHODS

Study area

Water quality sampling in the study area was divided into 3 regions based on the major tributaries of the Selenge River in Mongolia (Figure 2). In the northeast taiga focus area (NT), sampling was conducted on the Yeroo, Kharaa, and Sharyn rivers. In the southern central steppe focus area (CS), sampling was conducted on the Tuul and Orkhon rivers. In the western focus area (W), sampling was conducted on the Eg River flowing from Lake Huvsgul and the upper Selenge River, with headwaters in the Sangilen and Hangayn mountains. Abbreviations for specific river sampling sites used in the text are shown in Figures 2 and 3 and Tables 2 and 3. Information regarding the history of gold mining in the Selenge River watershed region was collected based on interviews with local authorities and industry officials. The information was verified by the authors to the extent practical.

To further investigate mining impacts, we also collected a higher spatial and temporal density of samples in 2 areas (Figure 2): the Steppe Focus Area, encompassing the Zaamar mining district of the Tuul River within the CS region, and the Taiga Focus Area, above the town of Bugant on the Yeroo River within the NT region.

The Taiga Focus Area includes the Bugant area, a mountainous area with birch, larch, and pine forest and grass valleys in the lower elevations. The Yeroo River flows from its headwaters in the Khan Khentii, a nationally recognized strictly protected zone in Mongolia (Y4) past Bugant township (Y2), to the confluence with the Orkhon River (Y1). In the 1970s, watershed rivers and floodplains were strip-mined by gold mining companies of the former Soviet Union. It was estimated that 650 tons of gold were removed from the region (P. Bierbaator, personal communication). Field observation found that little vegetative regrowth had occurred on tailing piles and dredge pits over the intervening 3 decades. Currently, mining has extended to smaller tributary drainages entering into the main stem of the Yeroo. These tributary drainages are undergoing the complete removal of soil and alluvium down to bedrock.

The Steppe Focus Area includes the Zaamar region, composed of rolling hills of steppe grassland at low elevation. Because of intensive mining activities (mining claims total over 70,000 ha), a transect was sampled along the Tuul River through this area. The Tuul River arises in the Khenti Range, flows southward past the capital city of Ulaanbaatar, and then curves northward to join the Orkhon River (Figure 2). Ulaanbaatar is located approximately 500 km upstream of Zaamar. The transect started above most mining activities, proceeded downstream, and ended at the confluence of the Tuul and Orkhon rivers.

Time period

Water quality surveys comparing the NT, CS, and W regions of the Selenge River watershed were conducted in August 2001. More detailed monitoring of the Taiga Focus Area (Figure 3) was conducted in August 2001 and September

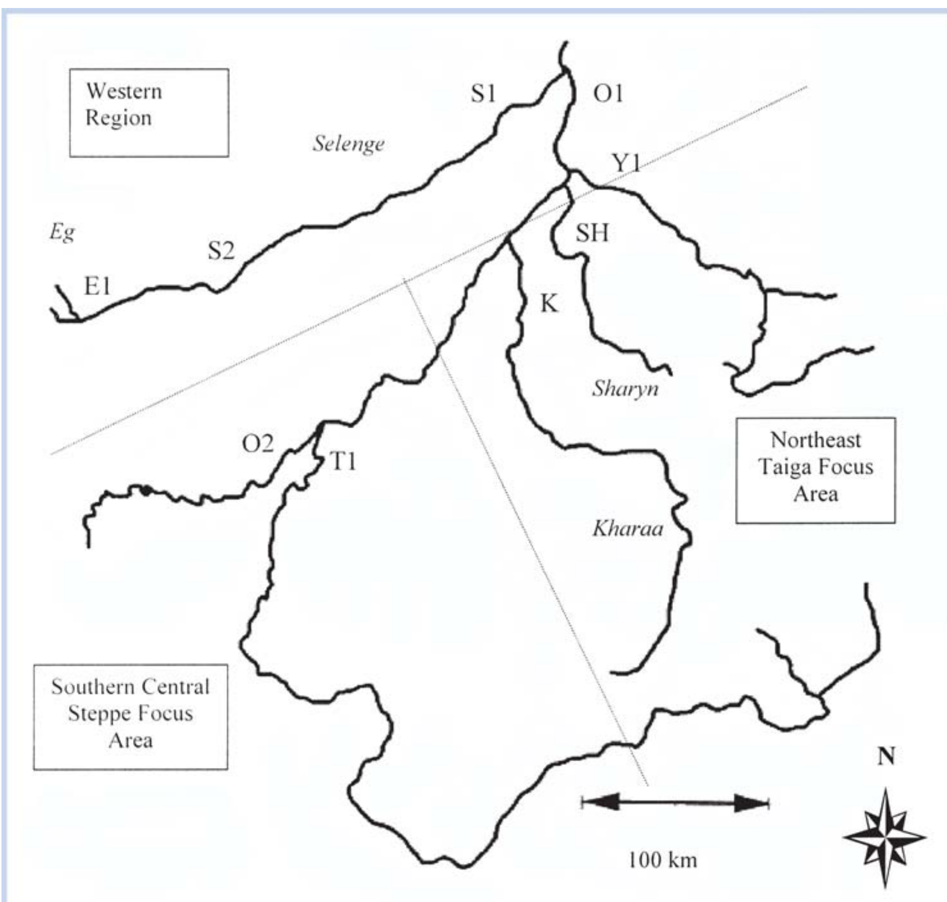

Figure 2. Multi-river assessment. Names of rivers are in italics. Codes for sampling locations are described in Table 2.

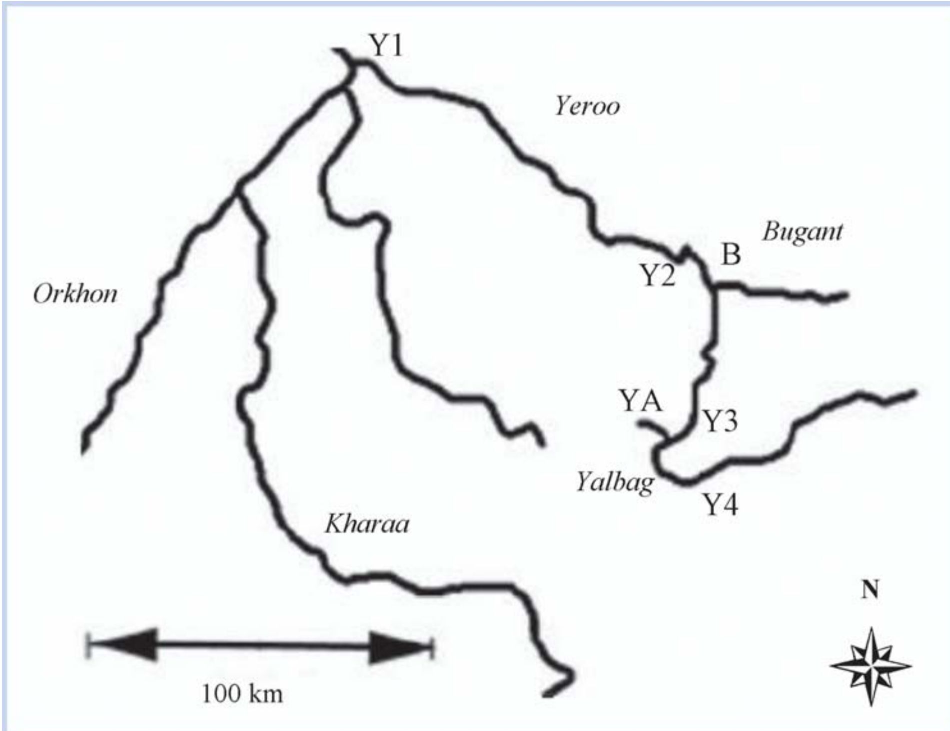

Figure 3. Map of the Northeast Taiga Focus Area: Bugant region of Yeroo River. Codes correspond to the following locations: Y1 = Yeroo River close to terminus; Y2 = Yeroo River just above Bugant Town and Bugant River; Y3 = Yeroo River just above Yalbag Tributary; Y4 = Yeroo River in Khan Khentii Ecological Reserve, above mining activities; YA = Yalbag Tributary, strip mining activities ongoing in 2001; B = Bugant Tributary, ongoing mining activities in 2001.

2003, and in the Steppe Focus Area in August 2001 and August 2002 (Table 2, Figure 2).

Water quality

Depth-integrated water samples were collected with a USGS DH-59 suspended-sediment sampler (Wildlife Supply, Buffalo, NY, USA) at 2 to 3 equal width intervals throughout the cross-section. Water was placed in a churn splitter (Bel-Art, Pequannock, NJ, USA) to maintain a homogeneous mixture of constituents. Dissolved oxygen, turbidity, and salinity were measured on site using portable instruments. Total suspended sediment (TSS) were filtered through

Table 2. Water quality assessment site locations

River	Site	Location	Sample dates
Bugant R	B	First bridge above confl with Yeroo R	18 August 2001; 20 September 2003
Eg	E	Confluence with Selenge R	10 August 2001
Kharaa	K	Above town of Darhan, nr Orkhon R	12, 20 August 2001
Orkhon	O1	First bridge above confl with Selenge R	7 August 2001
Orkhon	O2	Confluence with Tuul R.	11, 21, 25 August 2001
Selenge	S1	First bridge above confl with Orkhon R	8, 19 August 2001
Selenge	S2	Bridge at Hualgant Town	24 August 2001
Sharyn	SH	First bridge above confl with Orkhon R	19 August 2001
Tuul	T1	At confluence with Orkhon R	11, 21, 25 August 2001
Tuul	T57-T133	57–133 km above confl with Orkhon R	23 August 2001; 1 August 2002
Yalbag	YA	At confluence with Yeroo R	17 August 2001; 22 September 2003
Yeroo	Y3	Above Bugant Town	18 August 2001
Yeroo	Y2	Below Bugant Town	17 August 2001; 20 September 2003
Yeroo	Y5	Headwaters in Khan Khentii Reserve	16, 17 August 2001; 24 September 2003
Yeroo	Y4	At confluence with Yalbag R	17 August 2001; 22 September 2003
Yeroo	Y1	First bridge above confl with Orkhon R	7, 18 August 2001

Table 3. Results of the water quality assessment of the mongolian portion of the Selenge River watershed

Site[a]	Discharge ($m^3 \cdot s^{-1}$)	Suspended sediment ($mg \cdot L^{-1}$)	Load ($t \cdot d^{-1}$)	Turbidity (ntu)	Total phosphorus ($\mu g \cdot L^{-1}$)
First sampling 7–12 August 2001					
E	NA[b]	27	NA	24	NA
K	5	13	7	6	NA
O1	70	39	236	21	67
O2	25	68	144	25	NA
S1	540	146	6,800	85.2	NA
T1	11	59	55	47	NA
Y1	26	7	16	6	14
Second sampling 18–24 August 2001					
K	7	20	13	12	43
O1	125	37	401	45	102
O2	27	27	62	31	69
S1	577	24	1,211	20	58
S2	434	11.5	438	3	28
SH	2	39	5	31	129
T1	15	74	96	111	206
Y1	51	32	140	28	39

[a] Site locations given in Table 2 and Figure 2.
[b] NA = no data available.

preweighed nylon filters (1.2 μ, MSI Lab Filters, Westborough, MA, USA). The samples were then air-dried and returned to the Tahoe Research Group (University of California–Davis, Davis, CA, USA.) for reweighing. The TP samples were collected in 60-ml vials for analysis by the same laboratory. Analysis of TP was conducted using acid persulfate digestion followed by ascorbic acid molybdenum antimony (APHA 1989).

Loading calculations

Discharge was determined from bridges or by wading, where possible. The cross-section of the river was divided into equal widths using a suspended measuring tape. Flow was measured at the 6/10ths depth (representing average velocity) in each width increment, using a Global Oceanics flow meter (Miami, FL, USA). The flow meter was attached to a lead sonde to hold position in high-velocity flows. In 2003, a Swoffer Instruments (Seattle, WA, USA) digital flow meter was used to record flow velocities. Flow velocities were multiplied by cross-section areas and average TSS concentration to yield instantaneous sediment-loading rates. In the absence of continuous discharge information, it was not possible to make estimates of monthly or yearly loads.

RESULTS AND DISCUSSION

Selenge watershed assessment: Sediment loading and concentration

Two broad-scale assessments were performed during high- and low-flow conditions. During the 1st assessment, river levels were high for western rivers. The Eg River (E) was at flood stage, and the Selenge River (S1) and the upper Orkhon River (O2) carried high loads of TSS (Table 3). The northern taiga rivers, Yeroo and Kharaa, remained low. During the 2nd assessment, rainstorms in the NT region raised river levels, offering the opportunity to assess conditions under higher flow levels (Table 3). In the NT region, TSS loads doubled between the 1st and 2nd assessments for the Tuul (T1), Kharaa (K1), and Orkhon (O1) rivers. The total daily mass of TSS moved by the Yeroo River (Y1) increased 9-fold during this time, increasing from 16 tons per day ($t \cdot d^{-1}$).

Within the context of large shifts in loading rates as a result of regional storm systems, a few patterns emerged. We found that the Sharyn and Kharaa rivers appear to be small contributors to the overall sediment budget of the NT region. Of the rivers draining from the NT and CS regions into the Orkhon River, the Tuul River (T1) consistently had the highest TSS concentrations and carried the largest suspended sediment loads. On the 2nd sampling date, the Tuul River was transporting larger sediment loads than the upper Orkhon River (O2), despite having only approximately half the discharge. One exception to the predominance of the Tuul River loading was observed for the Yeroo River drainage (also an active mining region) during the latter half of August. The Yeroo River (Y1) doubled in volume as a result of rainstorms before the 2nd sampling period, resulting in a 9-fold increase in TSS load. A comparable increase in volume was not observed for the Tuul River during the period of the study. TSS loading from the main stem of the Selenge River (S1) was 29 times greater than the TSS loading from the Orkhon River (O1) during the 1st assessment.

The size of the Selenge River in relation to its tributaries (540 $m^3 \cdot s^{-1}$, or ~5–7 times the discharge of the Orkhon River) shows its importance to overall sediment loading. These results, however, do not indicate that the W region has worse water quality or watershed conditions then the NT and CS regions. A table of typical flow volumes for August provided by the Mongolian Institute for Meteorology and Hydrology (excerpted in Table 1) indicates the Selenge River had normal discharge for this time of year; however, the NT and CS rivers were only flowing at 20 to 30% of their August means. If the Tuul, Orkhon, and Yeroo rivers had been flowing at higher levels, it is likely that the TSS load would have been much higher because higher flows mobilize in-stream stores of sediment (Knighton 1998). For example, the Yeroo River experienced a 9-fold increase in TSS load with a doubling in discharge between the 1st and 2nd assessments (Table 3). Furthermore, the ratio of the Selenge River TSS load to that of the Orkhon River dropped from 29 to 3 between those periods.

The water quality of the W region appears to be excellent. Sampling conducted at Hualgant, upstream on the Selenge River (S2), indicated exceptionally low turbidity and TSS (Table 3). The TSS load at 52 was 33% of the downstream load (S1) measured 1 week prior. Further evidence of the water quality of the upstream portions of the western region comes from the single assessment of the Eg River. At the confluence with the Selenge River (E), the Eg River is roughly the same size with a mean August discharge of 256 $m^3 \cdot s^{-1}$, as compared to 292 $m^3 \cdot s^{-1}$ for the Selenge (Table 1). Discharge was not measured during the 10 August sampling because the river was at flood stage (flowing over its banks) and there was no bridge. For this reason, loads could not be calculated; however, the turbidity and TSS were quite low at 24 nephelometric turbidity units (ntu) and 27 $mg \cdot L^{-1}$ respectively, especially considering the river was at flood stage. The Eg River drains out of Lake Huvsgol, a subalpine lake with exceptional water clarity (Goulden et al. 2000) and provides a strong indication of low TSS loading in the west–central region. For the NT region, the regional assessment showed high TSS loading for the Tuul River and the Yeroo River, particularly in the 2nd half of the month.

An evaluation of the accuracy of the loading measurements can be performed by summing TSS loads from upstream stations and observing whether this load is measured at downstream stations. For the 1st assessment, the loading sum of 222 $t \cdot d^{-1}$ for the Yeroo (Y1), Kharaa (K), Tuul (T1), and Orkhon (O2), corresponds closely with the 236 $t \cdot d^{-1}$ measured for the terminus of the Orkhon (O1). Similarly, for the 2nd assessment, river loadings sum to 316 $t \cdot d^{-1}$can be compared with 401 $t \cdot d^{-1}$ for the terminus.

A 44-year record of sediment loading from the Russian reaches of the Selenge at Mostovoy gives an average daily load of 5,545 $t \cdot d^{-1}$ (Korytny et al. 2003). This is comparable to the 1,211 to 6,800 $t \cdot d^{-1}$ reported here.

Selenge watershed assessment: Nutrient loading and concentrations

Total acid-hydrolyzable phosphorus was determined for 2 locations in the 1st assessment and 8 locations in the 2nd assessment (Table 3). The rise in TP levels from the 1st to the 2nd sampling trip matches the rise in sediment concentrations for this time period. TP is usually found adsorbed to particulate matter, so TP concentrations increase with increased sediment concentrations (Wetzel, 1983). In the Selenge watershed overview provided by the late August sampling, the Tuul River had TP concentrations that were 200 to 300% of concentrations found on the other sites. Because floodplain soils of the Selenge basin have been found to be high in TP (Ubuganov et al. 1998), it is likely the elevated levels of TP observed in this study are a result of floodplain disturbance caused by mining operations. Other sources of TP could be municipal sewage inputs from Ulaanbaatar, 500 km upstream. The Sharyn River was unexpectedly high (128 nl/L) given its location between 2 similar rivers with lower levels. The Sharyn River had a higher temperature (21°C) and much lower flow rates than the Yeroo (15°C) and Kharaa rivers (18°C, Table 3), suggesting that the high concentrations are an effect of reduced flushing in slow-moving stagnant water. Additionally, high densities of livestock were observed in and around the channel.

Dissolved oxygen and salinity showed fewer differences between regions and between sampling dates than was seen for sediment and turbidity. Dissolved oxygen levels ranged between 6 and 10 μl/L. Trends followed typical patterns of being higher in headwaters (Berner and Berner 1987). The highest oxygen level (8–10 μl/L) was recorded for the Eg River, followed by the Kharaa River (8 μl/L) and the headwaters of the Yeroo River (Y4), above mining or human habitation (8 μl/L). The lowest levels were recorded for the Tuul (T1) and Orkhon rivers (O2) during the 1st sampling trip (6 and 5–6 μl/L, respectively).

Salinity was in the range of 21 to 171 $mg \cdot L^{-1}$. The lowest values were found in the headwaters of the Yeroo River (Y4), and the highest values were observed for the Tuul River (140 $mg \cdot L^{-1}$), Kharaa River (148 $mg \cdot L^{-1}$), and the Sharyn River (171 $mg \cdot L^{-1}$). Salinity did not show a correlation with TSS loading. For example, Yeroo River (Y1) sediment loading increased substantially over the month (16–140 $t \cdot d^{-1}$), but salinity fell slightly (54–43 $mg \cdot L^{-1}$). Salinity can act as a measure of groundwater interactions with surfacewater, the residence time of water in the stream, and weathering conditions in the watershed (Wetzel 1983). Our results suggest that the high mountain areas of the Yeroo headwaters have less weathering and less groundwater influence than low-lying floodplain reaches such as the Tuul and Orkhon rivers.

The Selenge watershed assessment conducted during 2 periods in 2001 shows that the rivers of west–central Mongolia (W) are generally lower in TSS loading and TP concentrations than the central regions (NT and CS). Higher central-region loading may be the result of increased land disturbance as a result of the placer mining in the area. As a result, we focused on finer-scale impacts of mining in 2 focus areas in eastern Mongolia (Bugant and Yalbag rivers) where active mining occurs, to determine the direct impacts of mining on the water quality of Mongolia's large and small rivers.

Taiga Focus Area

Elevated turbidity, TSS, and TP concentrations in tributary drainages undergoing active mining were found in both 2001 and 2003. In contrast, sites above mining activities showed very low values for these water quality parameters, indicating pristine conditions (Figures 3 and 4).

Site Y4 was located above all mining activities (Figure 3). During the 2001 expedition, TP and TSS were not measured; however, turbidity was extremely low. Because TSS and TP

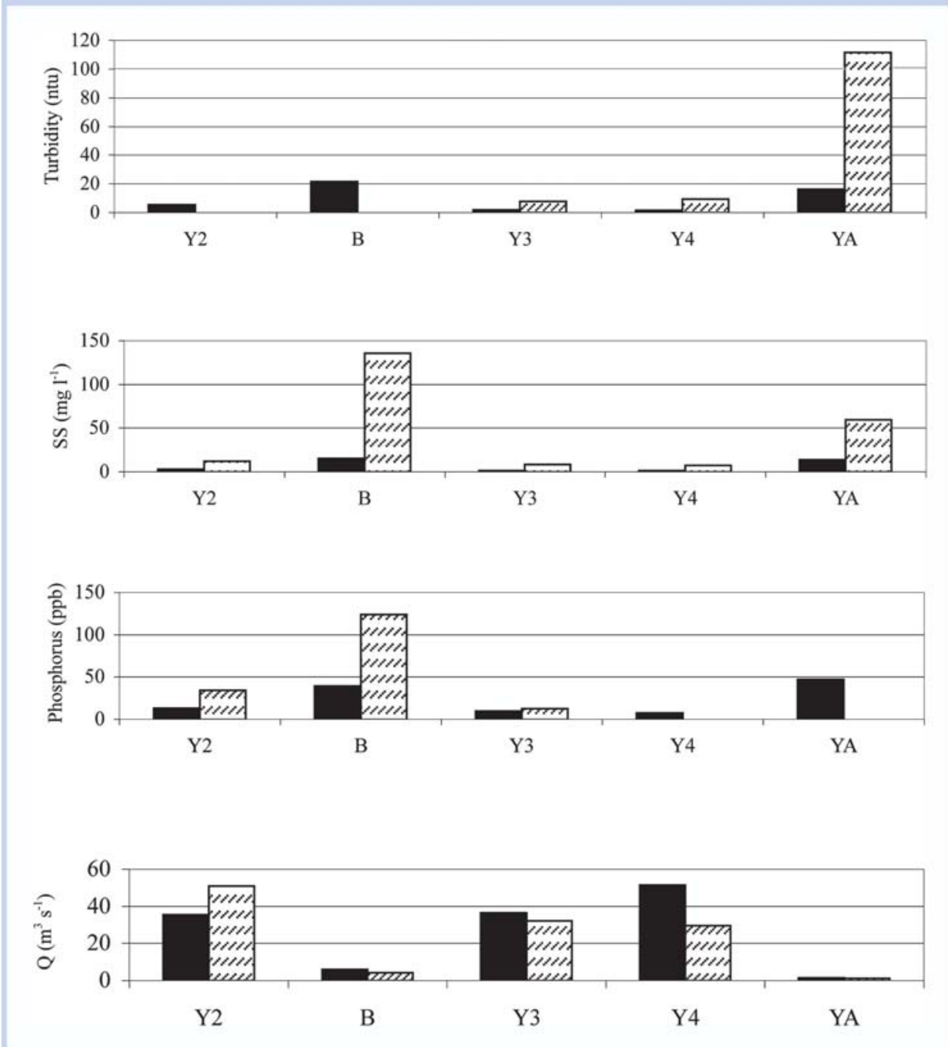

Figure 4. Northeast Taiga Focus Area: water quality assessment. Dark bars for sampling 16–18 August 2001, Light bars for sampling 20–24 September 2003. Discharge for Yeroo River just above Yalbag Tributary (Y3) estimated from site Yeroo River in Khan Khentii Ecological Reserve, above mining activities (Y4). Phosphorus = total acid hydrolyzable phosphorus; SS = total suspended sediment concentration; Q = discharge.

are strongly correlated with turbidity (Kronvang et al. 1997), it is likely these values were also extremely low at Y4. Samples taken from the Yeroo River just above the Yalbag River (Y3) indicate very low TP and TSS concentrations. Similarly, in 2003, very low concentrations of turbidity, TSS, and TP were recorded at Y3 and Y4.

In contrast, tributaries with mining activities showed high turbidities, TP, and TSS. In 2001, the Yalbag tributary (YA) had 15 times higher turbidity and 7 times higher TSS than the Yeroo River at their confluence (Y3, Figure 4). In 2003, YA had 8 times higher turbidity, 5 times higher TP concentration, and 11.5 times higher TSS than the Yeroo River (Y3). On the Bugant tributary (B), the TSS concentration for 2001 (135.2 mg/L) was 13 times higher than the Yeroo River at their confluence (Y2, 11.9 mg/L). TP was 3.6 times higher. In 2003, Bugant tributary (B) was 4 times more turbid and had 5 times more TSS and 3 times more TP.

In some mined watersheds, settling ponds are constructed by damming up the mouth of tributaries with the excavated fill. In the short run, the dams reduce sediment loading to the main stem and, therefore, lower the turbidity, TSS, and TP. However, by blocking the entrance to the channel, the dams result in the loss of the stream habitat for spawning fish and other aquatic organisms. Without maintenance, these loose earthen dams will fail and release large quantities of sediment to the Yeroo River.

Steppe Focus Area

Sampling in the Zaamar region indicates a decline in the water quality of the Tuul River as it flows through the mining region (Figure 5). In 2001, minor increases in suspended sediment concentrations (from 92 to 117 mg/L) and turbidity (from 61 to 85 ntu) were observed moving downstream through the mining region and below. However, TP more than doubled in concentration (increasing from 74 to 185 nl/L). Below the mining region (T25, T35, Table2), turbidity levels remained the same, and TP and TSS concentrations dropped slightly. Dissolved oxygen increased slightly with downstream direction (from 7.4 to 8 mg/L) as did salinity (99 to 106 mg/L). However, the river discharge in 2001 was less than 23% of mean flow recorded by a long-term gauging station (Table 1). It was suspected that during higher flows, the effects of flood-plain mining would be more pronounced. This was borne out by the 2002 sampling, indicating pronounced spikes in suspended sediment downstream of the dredge pits used for mining placer deposits (Figure 5). Higher flows would be

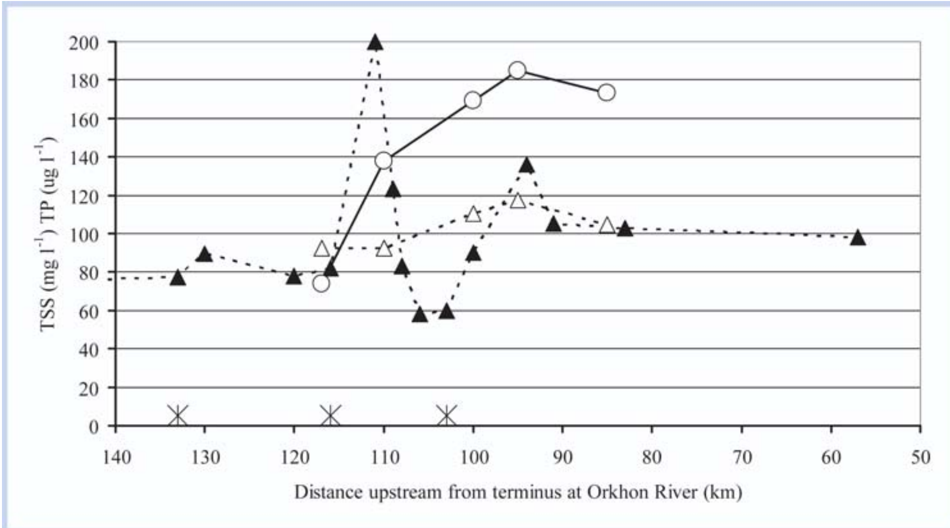

Figure 5. Southern central Steppe Focus Area: water quality assessment. Zamaar Region of Tuul River. Unfilled triangles and filled triangles indicate total suspended sediment concentration (mg/L) in 2001 and 2002, respectively. Circles indicate total phosphorus (μg L^{-1}) in 2001. Asterisk indicates locations of placer mines at km 133, 116, 103.

expected to cause larger TSS concentrations, especially if the dredge pits were to be breached. Discharge was not measured during the 2002 monitoring.

Ulaanbaatar, the capital of Mongolia, with a population of more than 700,000, is on the banks of the Tuul River. Batima (1998) reports that the Tuul River was the most polluted in Mongolia. Batima found the water quality degradation to be largely biological rather than chemical—a result of wastewater discharge. Although it is likely that the city is impacting water quality in the Tuul River, the large spikes in TSS values observed immediately downstream of mining activities in Zaamar (Figure 5) point to a local impact rather than loading from Ulaanbaatar 500 km upstream.

The other major environmental impact, although not measured quantitatively, is immediately obvious to any visitor to this region. The river terrace, extending to the visible horizon, is extensively disturbed, with 30 m–high tailing piles, cavernous excavations, dredge pits full of turbid water, and the complete loss of floodplain soil horizons over many square kilometers. Because of elevated soil moisture and floodplain deposition, low-lying floodplain areas often form the most productive grazing lands. Currently, more than half the population of Mongolia is supported directly or indirectly by the pastoral economy (Fenandez-Himenez 2000). Mining companies are legally required to rehabilitate the landscape; however, there has been very little effort to do so. As of 1999, the Zaamar region had 9,000 ha of disturbed land, of which only 29 ha had any restoration measures (Dallas 1999). Although the Tuul River can be expected to flush out fine sediment particles eventually, the loss of the rich floodplain pastures may pose a long-term threat to the sustainability of human settlements in the region.

CONCLUSIONS

It is difficult to draw strong conclusions from synoptic sampling because of the rapidly changing characteristics of rivers. Large floods, the rarest of hydrological events, can have the biggest impact, carrying the most sediment, and reworking channel and floodplain geometry (Knighton 1998). However, some indication of water quality characteristics and impacts is to be gained from rapid assessments of the type presented here.

In the mountainous source areas of the Bugant region, mining of tributary watersheds was associated with elevated concentrations of TSS, TP, and turbidity in tributary streams in both 2001 and 2003. Impacts on the main stem of the Yeroo River in this region were more limited. During rain events sampled in 2001, sediment concentrations increased sharply, suggesting the presence of easily mobilized, in-channel sources of suspended sediment. Visual inspection of the region (by jeep and on foot) indicated extensive disruption of valley landscapes.

Mining areas in the low-elevation steppe floodplains of the Zaamar region showed a slight increase in suspended sediment and a large increase in TP concentrations in 2001. Sampling in 2002 showed spikes of suspended sediment in reaches of the Tuul River downstream of mining dredge pits. It was apparent from the close juxtaposition of floodplain mining activities and the Tuul River that during flooding events large sources of extremely turbid water could be flushed into the river. Placer mining activity, as currently practiced in this region, results in the disruption of vast floodplain acreage. Mined areas were not being remediated, and very few safeguards were in place to prevent the introduction of suspended sediment into the fluvial system.

The large-scale assessment of water quality for rivers flowing into the Selenge in north–central Mongolia indicated excellent water quality for the Kharaa and Eg rivers and the Selenge River above Hualgant. The Yeroo and Tuul rivers, both intensively mined, showed higher concentrations of sediment and TP than other rivers in the region. The comparison of large rivers with different source areas was complicated by the timing of flood events. Monitoring that spans longer time periods is recommended to better integrate sediment and nutrient loads over a range of discharges.

As the Selenge River contributes more than half of the riverine input to Lake Baikal and 66% of the watershed of the Selenge River is in Mongolia, the condition of the upper Selenge watershed is of critical importance to Lake Baikal. Mining activity is rapidly increasing in Mongolia, with more than 30% of the country under license for mining (Farrington 2005). Many mining companies use outdated methods that contribute to poor water quality. Without proper environmental impact assessments and study of the impacts of mining, poor practices combined with increased mining activity may severely degrade the water quality of the upper Selenge River in the future. A comprehensive study is needed to determine the impacts of mining on water quality and river biota. Further growth of mining activities in the Mongolian portions of the Selenge River watershed could threaten Lake Baikal with increased sediment loading, increased nutrients, and loss of spawning habitat for migratory fish.

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