A Journey Down the Tuin: the Hydraulics of an Internal Draining River from the Khangai Mountains to the Gobi Desert

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ABSTRACT

River systems flowing through semi-arid and arid regions provide critical ecosystem services for inhabitants of these areas. In remote and/or difficult to access areas away from population centers, few direct measurements exist to characterize the nature of streamflow in these systems. The Tuin River flows from the rugged high mountain and forest steppe landscape of the Khangai Mountains in central Mongolia to its terminus at Orog Lake in the desert steppe and sand dunes of the northern Gobi Desert. Field measurements taken in June 2012 at numerous locations from river headwaters to mouth were used to characterize streamflow in the main river channel and associated floodplain. From these measurements, channel hydraulic characteristics were estimated and hydrologic properties were assessed using a digital elevation model and other spatial data. These properties include contributing area, slope, hydraulic radius, and channel roughness. During the low flow conditions of the survey, streamflow was decreasing from upstream to downstream. At a point between the Bayankhongor and Bogd gaging stations, streamflow ceased at the surface and reappeared approximately 10 kilometres downstream, exemplifying losing flow conditions and subsurface flow components. The results of this analysis could be scalable to other internally draining river systems, especially for hydrologic modelling.

Keywords: streamflow, hydrology, digital elevation model

INTRODUCTION

Mongolia is an arid to semi-arid country receiving between 30 and 500 mm precipitation annually (Venable et al., 2015). Rivers are often lifelines of the Mongolian rangelands, as they are a watering point for livestock and the nomadic pastoralist of the area. For the purposes of understanding water resources in parts of Mongolia, field data were collected to provide channel hydraulic information for hydrological modeling. This paper outlines the hydrologic and hydraulic data collected for the Tuin River in Central Mongolia (Figure 1a). As this river is an internal drainage, it is classified as a “losing” river in terms of flow.

METHODS

Fieldwork

Field measurements were made in June 2012 by a team of U.S. and Mongolian researchers. Starting at the headwaters of the Tuin River in the high mountain ecozone of the Khangai, streamflow and hydraulics cross-sectional measurements were conducted along the length of the river to its terminus at Orog Lake in the desert steppe (Figure 1, Table 1).

Seventeen measurements of streamflow were conducted using standard hydrologic methodologies (Carter and Davidian, 1989). Sites were chosen carefully to minimize effects of vegetation and obstructions, braided channels, and meanders in the channel on velocity measurements (USGS, 1980). Field methods included affixing a meter tape to both banks of the channel and a using depth rod to take measurements across the channel width to calculate cross-sectional area. A standard Price-type rotating cup pygmy current-velocity meter was attached to the wading (depth) rod with velocity measurements made at each depth location. Since depths were always less than 1 metre, the average velocity was measured at 60% of the depth, as determined on the wading rod. The flow measurements and area calculations together yield the average discharge at the site in cubic meters per second.

Additionally, eight hydraulic measurements of the main channel and adjoining floodplain were made to estimate channel roughness and to facilitate determination of bank full discharge and hydraulic radius for future modelling (Chow, 1959). Field notes were made of vegetation characteristics and channel/floodplain sediments to further assist with roughness estimates. In the headwaters regions where channel conditions were more compact due to topographic relief, entire cross-sections could be measured. In more distal portions of the river, measurements could only be made near the main channel as the floodplain stretched several kilometers away from the channel.

Geospatial

The locations of each field site were recorded using GPS. These locations were entered into a geographic information system (GIS) for further analysis of area contributing to each measurement point. Estimates of main channel stream length and gradient (slope) were made using a digital elevation model of the region at a 30-meter resolution (NASA, 2012). The area contributing to each measurement point was delineated using the ArcGIS Hydro Tool (Maidment, 2002; Djokic, 2008; ESRI, 2009). The software tool includes methods for terrain preprocessing, generating watersheds (catchment delineation), and generating stream networks.

Point locations from the field sites were used for delineation as well as stream gage locations provided by the Mongolian Institute of Meteorology, Hydrology, and the Environment. Minor adjustments to reflect additional location information or due to the use of the software tool were needed to generate the basin contributing area estimates. For example, the Bayankhongor gage location used in the basin analysis was relocated 1.3 km from the given GPS location.

Hydrologic and Hydraulic Analysis

Standard hydrological assessment included a comparison of streamflow and gradient along the Tuin River (e.g., Chow, 1959). By combining the GIS-based analysis with the field measurements, we estimated the unitless channel roughness (*n*) from Manning’s equation:

$$V = 1/n\, R^{2/3}\, S^{1/2} \qquad \text{[Eq. 1],}$$

where V is the average channel velocity in m/s computed from the streamflow per unit area, R is the hydraulic radius in m computed as the area per unit wetted perimeter, and S is the slope (Chow, 1959). From our data, V was computed from streamflow (Q) and area (A), R from A and depth, and S from the GIS analysis.

Table 1. Contributing drainage area, main channel segment length, and gradient for each field sampling site derived using the Arc Hydro Tool. The Manning's *n* roughness coefficient was computed using Equation 1. (Note: * Site Q03 includes the junction with the major tributary branch to the east, segment length is of the main westernmost channel.)

Tuin Site Name	drainage area [km^2]	segment length [km]	gradient [m/m]	streamflow [m^3/s]	Manning's n [unitless]
above Erdenetsogt	920	27	0.011	N/A	N/A
at Bayankhongor	2436	84	0.007	N/A	N/A
Q01	2621	89	0.008	1.79	0.053
Q02	2777	105	0.007	0.386	0.051
Q03	5596	133*	0.006	0.907	0.063
Q04	5721	136	0.006	1.14	0.075
Q05	5973	142	0.006	1.07	0.100
Q06	6489	172	0.005	1.14	0.117
Q07	6498	175	0.005	0.860	0.064
Q08	6662	194	0.005	0.427	0.070
Q09	6675	196	0.005	0.337	0.076
Q10	6682	198	0.005	0.084	N/A
Q11	6683	199	0.005	0.054	N/A
Q12	6684	200	0.005	0.019	N/A
above Jinst	6693	201	0.005	N/A	N/A
at Bogd	7524	240	0.005	0.191	N/A
above Orog Lake	7540	249	0.005	0.012	N/A
terminus at Orog L.	7561	258	0.005	N/A	N/A

RESULTS AND COMMENTS

When the measured streamflow was standardized by area, it decreased with area, as is expected of a losing stream system. However, all measurements except one were downstream of Bayankhongor and most of the drainage areas were larger (>5000 km^2), so the variation of drainage area with streamflow is difficult to interpret. It should be noted that discharge ended above Jinst as it all became subsurface flow, similar to what is observed in other closed basins (e.g., Valdez, undated). This loss of streamflow reduces the amount of surface water, but increases groundwater reserves. This groundwater-surface water interaction needs to be considered in conjunction with climate change for future water resources management. Streamflow subsequently reappeared above the Bogd gauge as groundwater discharge.

The estimated slopes derived from GIS are all shallow, with most gradients being about 0.5% with the maximum upstream gradient being 1.1% (Table 1). It was expected that further downstream gradients would decrease (Fassnacht, 2000). For the segments examined herein, the change in elevation was at a rate of -3.74 m/km with an almost perfect linear fit.

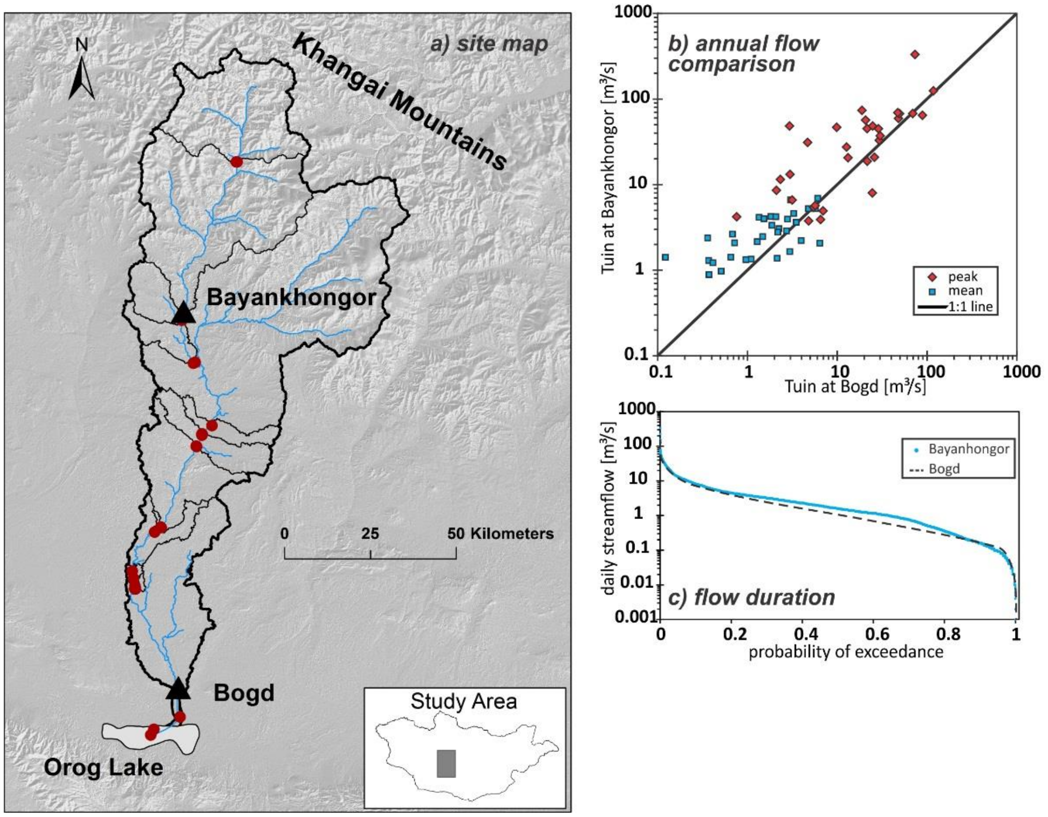

Figure 1. a) The Tuin River basin in central Mongolia, with the long-term streamflow gauging stations at Bayankhongor and Bogd and the measurement locations, b) comparison of annual mean and peak streamflow for the Tuin River at the Bayankhongor versus the Bogd gauging stations, and c) flow duration curves for the Tuin River at the Bayankhongor and Bogd.

Streamflow along the Tuin River at Bayankhonger tends to be greater than at Bogd (Figures 1b and 1c). This is especially true for lower flows (shown as mean streamflow in Figure 1b and the flow duration curves in Figure 1c) that recharge groundwater, as seen during our 2012 survey. We saw the Tuin River end and reappear (as groundwater discharge) above Jinst (Table 1). Peak flows (shown as the annual maximum daily streamflow in Figure 1b) were generally greater upstream than downstream; however, these are not always generated from the same rainfall event due to the spatial heterogeneity of precipitation events in this region.

The Manning's roughness coefficient was computed from the slope and field streamflow measurements (Table 1). The channels became rougher as they become wider (Table 1). However, the range of computed *n* is too large to be considered realistic (0.051 to 0.117), likely since the actual change in slope is much more local than the slope computed from GIS. The channel cross-sections selected for flow measurement were considered representative as standard protocols were followed for site selection (Carter and Davidian, 1989).

In future work, it is recommended that cross-section data for the entire channel beyond bank full to across the flood plain should be used to further evaluate channel hydraulics, as the data captured here represents low flow conditions in the main channel of each area sampled. At each cross-section this includes computing *R* as a function of depth, and using photographs of each site to estimate *n* and then computing bank full and flood stage streamflow. High flows in these river systems cover much larger areas, which would likely change the estimates of channel roughness and slope needed for detailed modeling efforts.

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