Joint Summer 2011 Hydrology Field Campaign in Haean Catchment

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Abstract: An intensive hydrologic field campaign was completed in Haean during the month of July 2011 to characterize a broader distribution of contributing drainage areas, compare inconsistencies in previous data, and build a stronger hydrogeochemical dataset for TERRECO-based modeling activities. Results generally support previous discharge estimates, although they point out the likelihood of different annual discharge and stage relationships.

Keywords: *discharge, nutrients, biogeochemical samples, water quality*

1. Introduction

A hydrologic field campaign was completed in the Haean Catchment during the month of July 2011 which focused on research addressing several key questions that have developed in relation to field studies carried out during the past 2 years. Calculated estimates of the water balance at several locations suggested that the fraction of precipitation in each water compartment did not balance and that surface water runoff observations were uncertain. Accurate and consistent discharge observations were previously limited to a single monitoring location at the forest/field transition and at relatively high elevation. While other locations within the catchment were often monitored, the temporal frequency was limited.

The hydrologic response within Haean Catchment is extremely important to understand, because it directly affects nutrient and energy transport, erosion and sedimentation, and plant water requirements as needed for optimal agricultural production efficiency. The objective of this field study was to continuously monitor discharge for a wide range of drainage area sizes during the 2011 monsoon season and to examine the spatial and temporal dynamics in discharge that occur throughout the catchment. In order to clarify characteristics of water flows and to derive more accurate results, we compared and contrasted 6 different discharge measurement methods at 15 locations that varied in slope from 1 to more than 80%, with discharge variations up to 8 orders of magnitude. This enables us to weight the accuracy of each method over a discharge range.

2. Methods and Materials

2.1 Study Area

The Haean catchment study area is located in Yanguu Province, northeastern South Korea along the demilitarized zone (DMZ) between South and North Korea (Figure 1). The 62.7 km^2 catchment is one of the major agricultural areas providing flows into Lake Soyang and ultimately the Han River, providing a major drinking water source to the city of Seoul. The catchment has unique physiographic characteristics, climate and elevation variation (see Tenhunen et al. – TERRECO Geographical Setting – in this proceedings). Elevation ranges between 339 to 1321 m with an average slope of 28.4% and maximum slope of 84%. Geologically, the “punchbowl” shaped basin is composed of Precambrian gneiss at the higher elevations with Jurassic biotite granite intrusions that were subsequently eroded in the central portion of the catchment. The basin has a monsoon climate with an average temperature of 8.65±0.35˚C and ranging between -26.9˚C in January to 33.4˚C in August. Rainfall is focused during the monsoonal period between the months of June and July with 50% on average and up to 70% of the total annual precipitation. The average annual rainfall over the past 12 years is 1514 mm and ranged between 930 to 2299 mm/yr. Maximum precipitation has been 48.6 mm/hr or up to 223.2 mm/d. The average catchment outlet discharge is 37 m^3/s with an observed maximum of 258 m^3/s in August 2010 and low flow typically around 3 m^3/s.

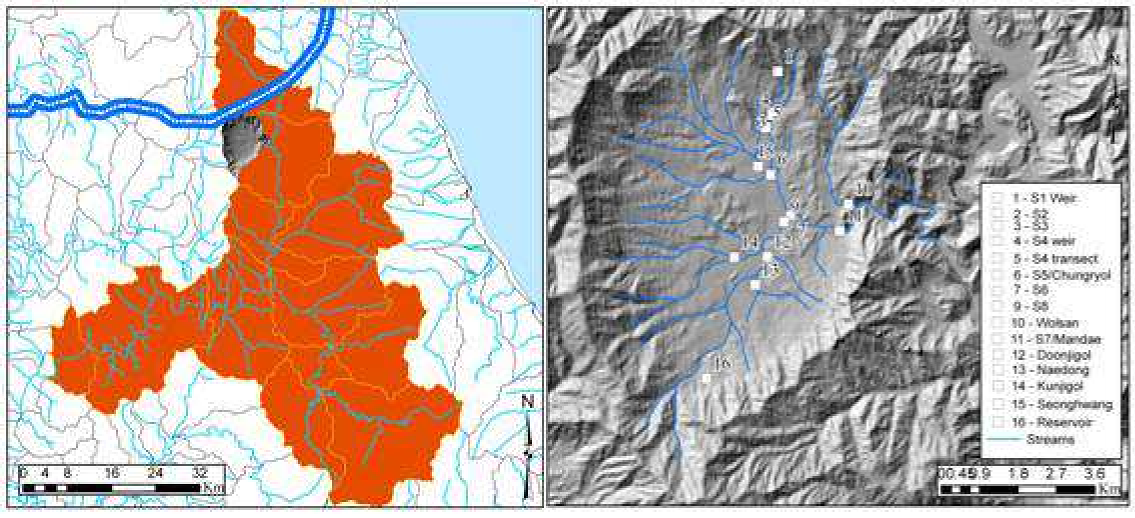

Figure 1. Haean study area within the Lake Soyang watershed is located in northeastern South Korea along the border with North Korea. Primary monitoring locations used during the 2011 hydrologic field campaign

2.2 Discharge Estimates

Discharge data was collected at more than 15 locations throughout the catchment from 2003 until 2011 as shown in Figure 1. The contributing drainage areas for each monitoring location ranges from 0.1 km^2 to the entire 64 km^2 (Table 1). Measured discharge was estimated via a variety of methods including: an Acoustic Doppler Current Profile (ADCP) boat, the in-stream velocity-area technique, dilution estimates with solute tracers, velocity derived estimates, timed volumetric estimates, uniform flow Manning formula discharge calculations, and multiple v-notch weirs (illustrated in part in Figure 2). At each location, multiple discharge estimates were completed and compared to create weighted discharge relationships for each location. Additionally, pressure transducers were also installed to continuously monitor the river stages. Subsequent stage/discharge rating curves were produced for continuous discharge estimates.

Figure 2. Surface water discharge can be measured with a variety of methods including the ADCP boat technique, the velocity-area technique coupled with automated stage height, velocity derived estimates with a buoyant object, and flow boards coupled with automated stage height at sites with a rating curve.

The ADCP uses a suite of 4 transducers at 25˚ slant angles operating at 3.0 MHz in conjunction with a 1.0 MHz vertical beam are used to profile the channel bathymetry, velocity distribution, and water discharge. The precise measurement location is determined with the onboard GPS unit and internal algorithms are incorporated to account for high streambed sediment moving-bed conditions. The ADCP system is initialized and calibrated at each site location prior to at least 3 transects across the width of the channel. Repeated measurements are used to estimate the discharge uncertainty and increase the method repeatability.

We also measured stream discharge repeatedly at multiple sites using the velocity area method (Buchanan and Somers, 1969; Rantz, 1982) with an Ott FlowSens flow meter. Profiles were collected in locations where channel geometry was favorable. Errors associated with these discharge measurements were calculated at less that 5-10%. Dilution salt tracer additions were used at several first-order, low flow locations throughout the catchment. Several variable volume salt slug injections based on the expected flow rate was added to the stream and the concentration was measured over time at a downstream location.

Table 1. Contributing drainage area for each sampling location

	area (ha)	area (km2)
S1 Weir	35.46	0.3546
S3	57.78	0.5778
S2	108.36	1.0836
S4	181.62	1.8162
S5/Chungryongangol	209.43	2.0943
S6	2214.54	22.1454
Wolsan	665.37	6.6537
Seonghwang	654.75	6.5475
Doonjeonggol	153.63	1.5363
Naedong	312.03	3.1203
Kunjigol	728.19	7.2819
Mandae	5207.76	52.0776
Catchment	6273.27	62.7327

The velocity derived discharge estimates were accomplished by calculating the time of travel of a neutrally buoyant object (an orange) over a fixed distance. The object was inserted at multiple locations across the channel width at multiple times and an average was estimated. The results were further related to the more accurate velocity-area and ADCP estimates. These estimates were accomplished at most locations in addition to alternative discharge estimates. Timed volumetric estimates were accomplished by simply calculating the time required to fill a known volume. These estimates were primarily accomplished in the smaller low-order stream sections.

Stream stage was measured using a fixed staff plate at most monitoring locations and/or a pressure transducer installed in the stream. Rating curves were developed for each site relating the discharge and stage and updated regularly to account for streambed changes in channel geometry.

To minimize the level of effort in estimating discharge, Manning's Equation for uniform flow in an open channel was also used. The Manning equation for discharge is expressed as:

$$Q = \frac{1.5}{n} A R^{2/3} S^{1/2}$$

where n is the Manning's roughness coefficient of the channel, A is the cross-sectional channel area, S is the channel bed slope, and R is the hydraulic radius in terms of area divided by the wetted perimeter. This equation limits the need for velocity measurements although increases estimate uncertainty through the incorporation of the roughness coefficient.

2.3 Water Quality Sampling

The same monitoring sites utilized in surface water discharge estimates were also used to collect nutrient and sediment samples starting as early as 2003. Samples were collected daily at 12:00 pm throughout the period of the campaign in 2011, and every 2 hours during precipitation events. In addition to the field parameters (temperature, pH, specific conductivity, and dissolved oxygen), samples are analyzed for turbidity, biological oxygen demand (BOD), chemical oxygen demand (COD), suspended sediment (SS), fixed and volatile suspended sediment (VSS), non-volatile suspended sediment (NVSS), total nitrogen (TN), nitrate as nitrogen (NO3-N), ammonia as nitrogen (NH3-N), total phosphorous (TP), dissolved total phosphorous (DTP), dissolved inorganic phosphorous (DIP), and dissolved organic carbon (DOC).

Several different monitoring experiments were completed to further examine spatial and temporal dynamics in nutrient and sediment concentrations in surface water and groundwater quality. Synoptic sampling was incorporated in which, all monitoring locations were sampled at nearly the same time. This allows us to analyze how concentrations varied spatially at the same time. During several events, groundwater and shallow subsurface samples were collected along 2 well transects; in addition, surface water samples were taken throughout the catchment. This enabled a spatio-temporal comparison of water quality in the interflow, shallow aquifer, deep aquifer, and surface runoff compartments which has not been completed to date. These samples are also planned to be analyzed for Deuterium (^{2}H) and Oxygen-18 (^{18}O) isotopes.

3. Results and Discussion

3.1 Cross-Section Channel Area

From the 2011 field campaign, it appears that all channel cross-sections monitored are shallow, wide, and relatively flat. This is expected in locations with high sediment transport; however, the range in streambed slope, discharge, and contributing area would suggest more variability in channel profiles [Figure 2 – waterfall plot of all areas].

3.2 Methods Comparison

Many discharge measurements have been made in Haean streams over the past several years. Although details are limited, it appears that in 2008 a group from the Civil Engineering Department of Kangwon National University installed stage height level boards at Chungryongol, Dunjigol, Kunjigol, Naedon, Sungheungwan, Wolsan, and Mandae. The group used the velocity-area streamflow technique to calculate 10 individual discharge values corresponding to stage height at those particular measurement times. The group then calculated the best fit power law equations for rating curve estimates. The Department of Environmental Science research team continued to use these rating curves in conjunction with the stage height to estimate discharge during monitoring events. In mid 2010, the team updated the level boards from painted markings on the sides of bridges to precise flow boards, which are currently in use. In 2009, a v-notch weir was installed at the S1 forest boundary location to continuously measure surface water discharge. A 2nd v-notch weir was subsequently installed in 2010 at S4. Since 2009, additional discharge measurements have been made using several methods including: solute tracers, the bucket method, velocity derived estimates, and additional velocity-area methods.

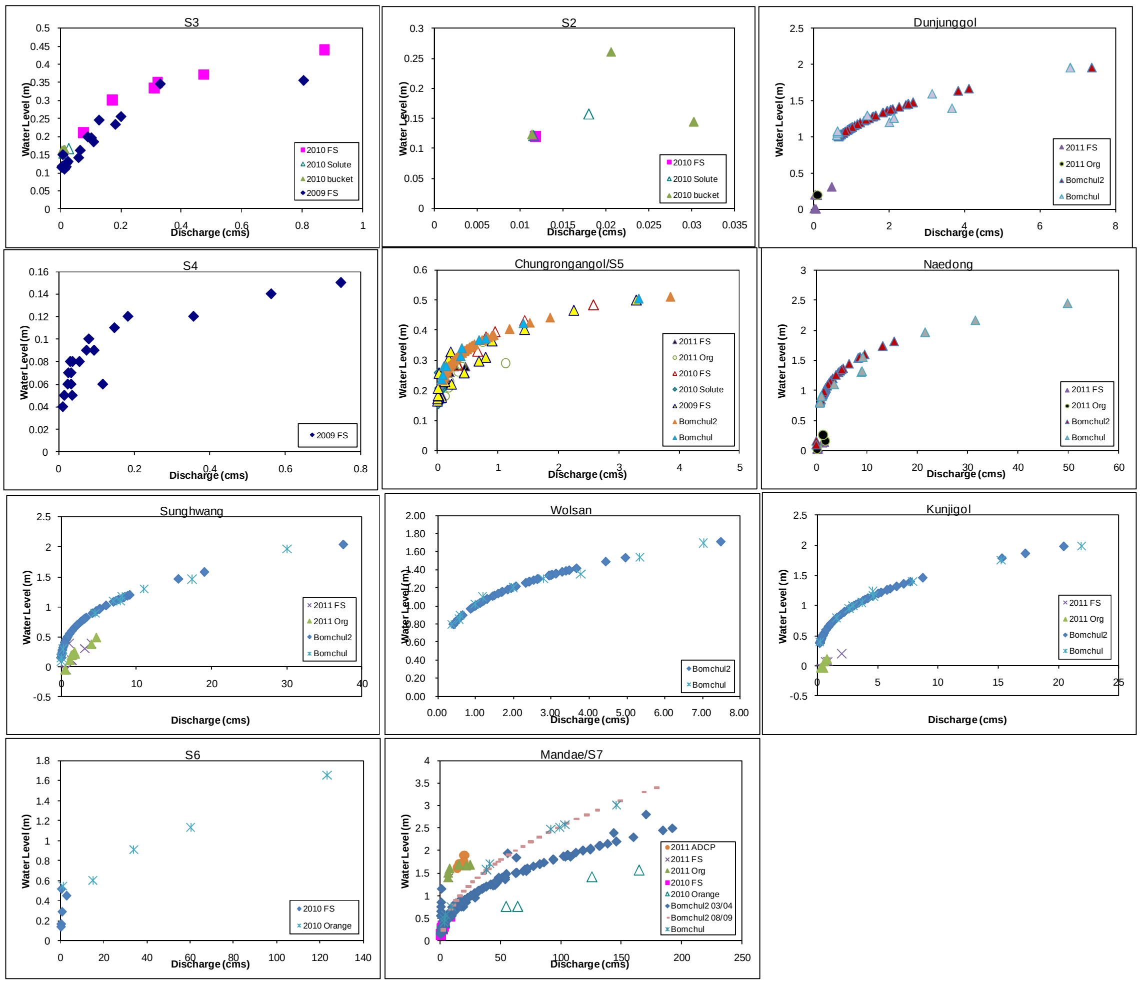

Figure 3. Discharge measurements relative to stage height at 11 Haean locations. Measurements include flowmeter (FS), solute injection (solute), timed volume (bucket), timed velocity (orange), and ADCP estimates from each of the data sources in addition to the 2011 data for comparison.

Initial analysis revealed that some estimates were not consistent between monitoring groups, methodological techniques, or over time. To that end, we decided to compare as many methods as possible at the same time to examine how accurate each method was relative to the more repeatable in-stream flowmeter measurements. We also wanted to collect discharge measurements from more locations throughout the catchment over a greater range of drainage areas than previously completed (Figure 3).

While analysis continues, it appears that the most accurate and repeatable measurements are with the velocity-area technique or the ADCP boat. The velocity-area technique was found to be repeatable and accurate when each measurement area was less than 10% of the total. When fewer measurements were made across the channel, uncertainty increased. The main drawbacks of the flowmeter was the length of time required to complete a measurement (~30 min) and the inability to use the method with increased stage height and corresponding velocity. While the ADCP reliability increases with stage height, the limitations of this method are streambed movement, channel depth, and instrument stability. In Haean, the streams are typically less than 30 cm deep with the exception of very extreme, short duration events, which prevents using this instrument. The high streambed and suspended sediment load also decreases instrument accuracy. While, the instrument has rigorous algorithms to account for bedload movement and boat speed when calculating the in-stream velocity, high particle concentrations limit the transducer sounding depth and provide inaccurate Doppler shift estimates. When these features are also coupled with high pitch and roll in the turbulent stream, transducers are not always aimed toward the bed and calculated values are estimated with unreasonable input data.

The discharge estimated by the “drifting orange” method was also compared to flowmeter or ADCP measurements and found to be nearly linearly related with a correlation coefficient greater than 96% at each site location. The solute injection method is limited to lower discharge in smaller streams primarily due to the mass of tracer required, the potential for complete mixing, and the length of time required for a complete measurement. The bucket method was also found to be very repeatable, although again limited to the smallest streams.

We continue to examine the Manning formula estimates as an alternative to the time-consuming and labor intensive manual measurements. We collected highly accurate laser derived slope estimates from multiple angles and each of the locations to calculate the streambed slope. We are also examining the DEM to assess if the larger scale land topography slope estimates are reasonable. We obtained highly accurate cross-sectional areas to flood stage at each location, which coupled with pressure transducers can provide continuous estimates of discharge.

3.3 Discharge with Distance Downstream

As would be expected, discharge increases with distance downstream and the contributing drainage area increases. The 2011 field data supports this conclusion from previous research. In addition, differential discharge gauging between sites S6 and Mandae was completed to estimate stream reach gaining or losing conditions. The reach has no adjoining streams, inputs, or outputs along the length. The reach was subdivided into 5 subsections on 23 July, 2011 and the discharge was estimated with the in-stream flowmeter and the orange method. Results suggest that that the low elevation valley floor is gaining. Discharge increased 33% along the length of the reach with estimate uncertainty less than 7%. These results further support gaining conditions as suggested by Bartsch et al. (Aquifer Exchange – in this proceedings).

4. Conclusions and Recommendations

Over 200 manual stage and surface water discharge measurements were completed and over 700 water quality samples were collected during July 2011 to increase our understanding of hydrologic flow partitioning, spatio-temporal nutrient loading, and sediment transport. The discharge data supported previous manual discharge measurements collected over the past 2 years and added valuable information for additional locations throughout the catchment. Multiple discharge estimation methods were used concurrently to provide a better understanding of the measurement precision, when the measurements are acceptable, and to support previous estimates.

Water quality samples were collected at the same locations as discharge samples were collected. Sample collection focused on a synoptic sampling scheme where all samples were collected at the same time to provide information on spatial variability. In addition, we sampled 2 groundwater transects in order to understand how peak events control flow patterns, and ultimately nutrient transport throughout the catchment.

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