BOARDMAN RIVER EXISTING-CONDITIONS SIAM MODEL FOR DAM REMOVAL STUDY

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Abstract A dam removal study is being conducted on the Boardman River near Traverse City, MI for the Great Lakes Fishery and Ecosystem Restoration (GLFER) program with the U.S. Army Corps of Engineers– Detroit District (USACE). The study extends from the mouth of the river at Grand Traverse Bay, through four dams to reconnect 24 miles of anadromous cold-water fish habitat. Hydropower had been generated at three of the four dams, but generation has ceased due to lack of economic viability. A historic sediment budget and a Sediment Impact Assessment Model (SIAM) were developed and calibrated to document existing sediment erosion, transport, and deposition patterns within the study reach and impoundments. The results of the SIAM modeling indicated that outside of the impoundments, the river is relatively stable. Over the lifetime of the dams, a significant amount of sediment has accumulated in some of the reservoirs. Calibration of SIAM required a number of iterative adjustments of sediment transport and particle size parameters to best match observed processes. Calibrated sediment budgets agreed with data for the sediment deltas at the upstream end of the two main reservoirs however, sediment budget deficits below two of the dams did not match observed field conditions. The results of these analyses indicate SIAM can be a useful tool for identifying general sediment budget trends and when more comprehensive sediment transport analyses and modeling are required. Final results will be used to determine which removal scenarios will be most feasible.

INTRODUCTION

The Boardman River is located in the northwestern portion of Michigan's lower peninsula and drains into Grand Traverse Bay near Traverse City (Figure 1). The river is a designated Natural River by the State of Michigan and includes 36 lineal miles of Blue Ribbon Trout Stream (Michigan DNR). The study area includes a 24-mile section of river from the US Geological Survey (USGS) gage upstream of Brown Bridge Dam to Boardman Lake, located within Traverse City. We completed modeling of the entire study reach to examine the current conditions of the river with all dams intact and estimate the total amount of sediment that has accumulated within the impoundments.

Site Description Four dams currently impound the water on the main branch of the Boardman River in the study area: Brown Bridge Dam, Boardman Dam, Sabin Dam, and Union Street Dam. Traverse City Light and Power ceased power generation at Brown Bridge, Boardman, and Sabin dams due to the lack of economic viability (Table 1). Studies have commenced on the fate of these structures, with a number of alternatives proposed, including complete removal.

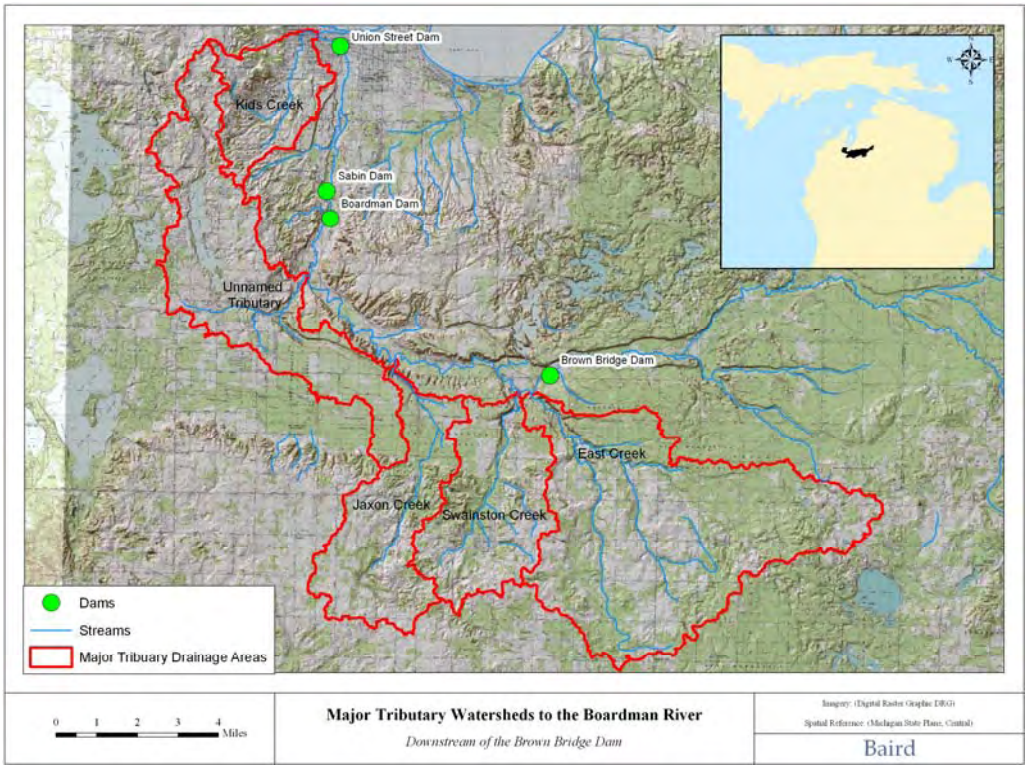

Figure 1 Location map of Boardman River dams and major tributaries.

Table 1 Dams on the Boardman River within the study reach.

Dam	Year constructed (updated)	River Mile (from Lake Michigan)	Watershed Area (mi2)	Impoundment Area (acres)
Brown Bridge	1921	18.5	151	191
Boardman	1894 (1930)	6.1	267	103
Sabin	1906 (1930)	5.3	269	40
Union Street	1867	1.5	291	339

METHODS

A SIAM (Sediment Impact Assessment Method) model was developed for the study area using a combination of literature review, field observations and data collection, analyses of historic discharge and sediment data, HEC-RAS modeling, and review of historic impoundment data.

Field reconnaissance was conducted along the Boardman River project study area during the summer and autumn of 2008. Fieldwork consisted of river channel sediment sampling and analysis, and the mapping of significant bank erosion sites. Flow and sediment sampling were conducted by the USGS, and channel sediment sampling and bank erosion site mapping were conducted by the U.S. Army Corps of Engineers – Detroit District (USACE). Sediment data from the USGS was collected at the gage site 04126970 (shown in Figure 2) upstream of Brown Bridge dam. This data was collected at several different flow rates and used to develop a sediment rating relationship at that location (Figure 3). Bed sediment data from several locations

along the river provided channel gradation data. Flow and sediment transport modeling was conducted using the results of the field reconnaissance.

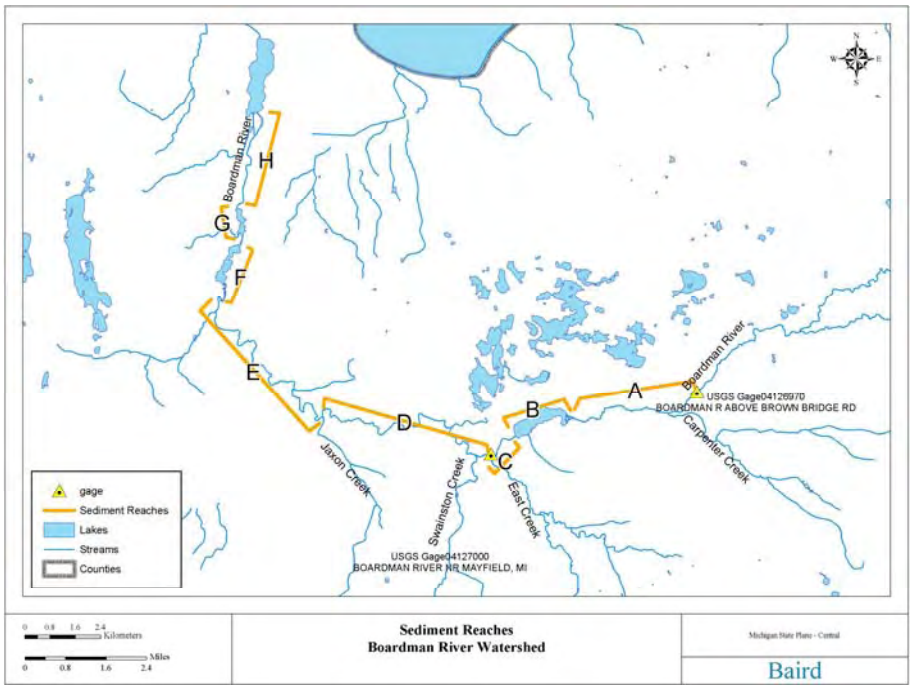

Figure 2 Unique reaches defined within the study area for modeling within SIAM.

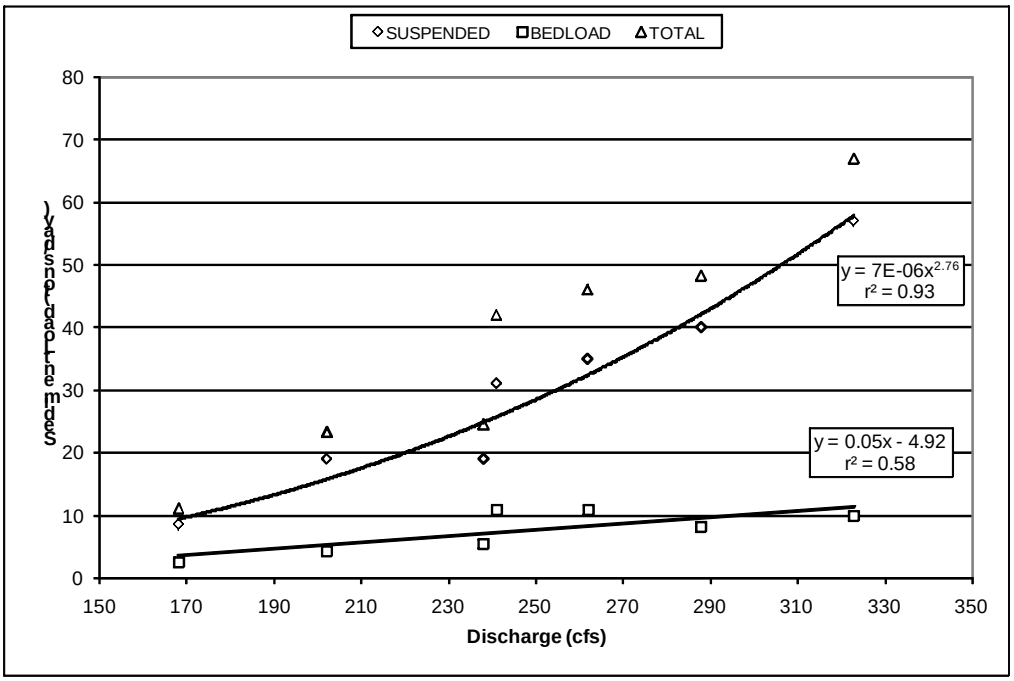

Figure 3 Sediment data collected by the USGS at gage 04126970, upstream of Brown Bridge Dam. From this data, we were able to estimate a relationship between flow and suspended and bedload sediments.

The study area was divided into eight different reaches (Figure 2) for modeling within SIAM. These reaches were differentiated based upon the bed sediment samples, channel slope, location of bridges and dams, and branching patterns of the river and its tributaries. The results of the bed sampling showed consistent grain-size distributions within each defined reach (Figure 4). The larger Brown Bridge Dam and Boardman Dam impoundments were divided into two distinct sections, impoundment and delta, to adequately represent the different bed sediment characteristics and hydraulics of the impoundments.

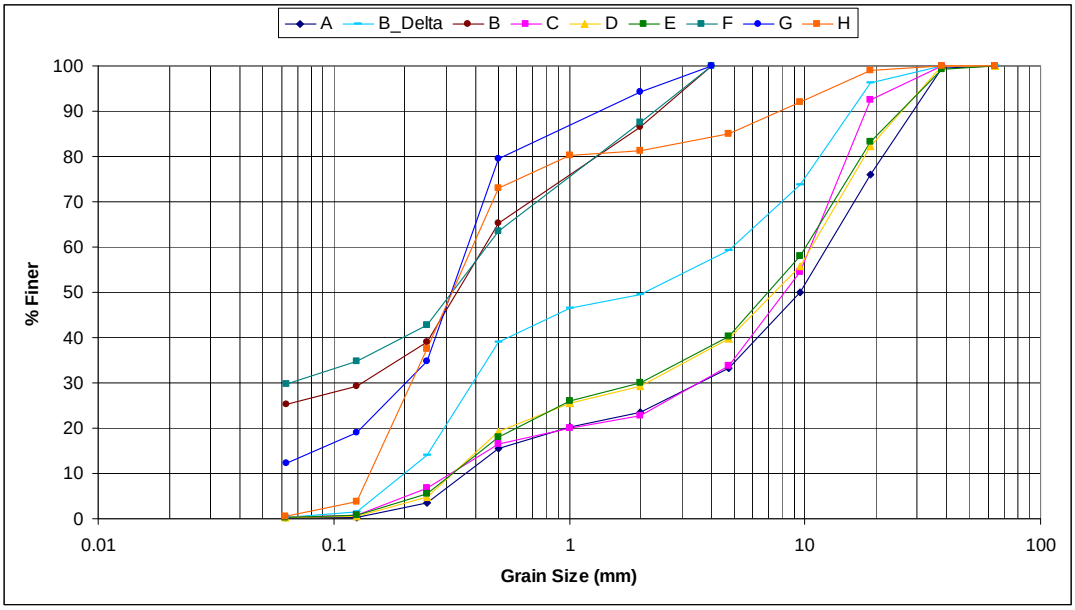

Figure 4 Representative particle size distributions for each reach of the study area of the Boardman River.

Hydraulic Modeling In order to estimate the total volume of sediment being transported through the Boardman River system under the existing conditions, a combination of methods was employed including hydraulic modeling and impoundment volumetric analysis.

The USACE developed a complete HEC-RAS (ver 3.1.3) hydraulic model for the Boardman River using a combination of existing hydraulic and flood models for the river and additional survey and structure data (USACE, 2008). The model included flood events with recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500-years from the Michigan Department of Environmental Quality (MDEQ) Hydrologic Studies unit for a number of locations along the Boardman River. These events were estimated using regional flood and precipitation relationships to predict flow as a function of a number of watershed and landscape parameters such as watershed area, watershed slope, contributing area, percentage watershed as lakes, percentage watershed as swamps, and soils and geologic properties (Farrand and Bell, 1984; Holtschlag and Croskey, 1984). Results from a simple linear regression of the data indicated that drainage area explained more than 95% of the observed variability in peak discharge (Figure 5).

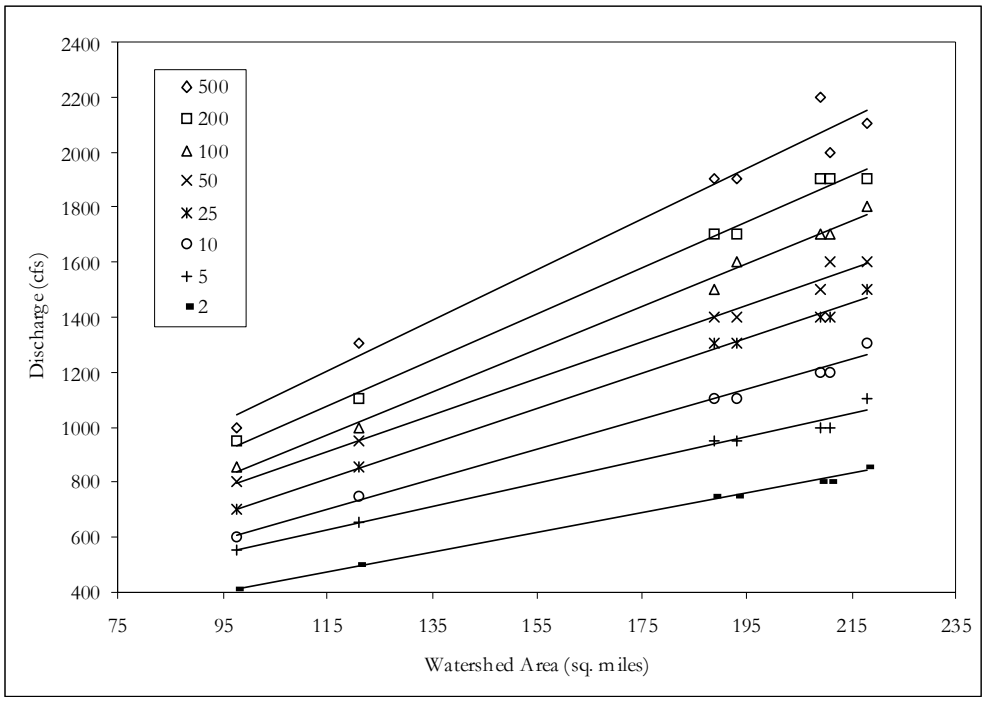

Figure 5 Regression of the 2 to 500-year discharge values based on watershed area for the Boardman River hydraulic model. Watershed area explains more than 95% of variability observed in discharge estimates.

SIAM Model SIAM is a tool that estimates annualized sediment budgets along a river by comparing transport capacity to sediment supply (from numerous sources) and reports sediment surplus or deficit on a reach-by-reach basis. The intended use of SIAM is as a screening level tool to determine where further, more detailed, analyses are required. Results from SIAM indicate general trends of surplus or deficit rather than mass of eroded or deposited material (USACE, 2006).

The upstream and downstream boundaries of the SIAM model were a USGS gage and the upstream extent of the Union Street Dam impoundment, respectively. Flow data for the entire period of record from the USGS gage upstream of Brown Bridge Dam (1997-2008) was used to develop an annualized flow series required by SIAM; the period of record did not include any design events. A historical stream gage, downstream of Brown Bridge Dam at Mayfield, Michigan, had a longer period of record but no overlapping data period to develop a relationship between the two gages. Historical precipitation data comparison between the periods of record for the two gages showed a 10% decrease in average annual precipitation, thus, simple scaling by watershed area was not sufficient to create an annualized series for a longer period of record. Analysis of the flow statistics revealed the two gages had similar frequency and distribution characteristics when flows were scaled by total range and median flows. Consequently, the frequency distribution and duration values for the Mayfield gage were used to extend the gage upstream of Brown Bridge Dam to include up to the 5-year event. Extrapolation to larger flows was deemed impractical due to lack of record and degree of gap length between the two gages.

The USGS gathered bedload data at several different flows at the gage upstream of Brown Bridge Dam. The results, shown in Figure 6, show very consistent gradation trends with discharge; any observed variation was within sampling uncertainty. These data were used to develop daily and annualized bedload data for the SIAM model. The data were scaled by watershed area for each reach becuase no other sediment data were available for the study reach. Major tributaries determined to be contributing sediment to the Boardman River based on field observations, shown in Figure 1 were included within the SIAM model. The annualized time series developed for the model was scaled by watershed size for these tributaries to provide boundary loading conditions. Swainston Creek has a large impoundment that acts as a sediment trap, consequently only the drainage area downstream of the dam for this tributary was used to estimate its sediment contribution.

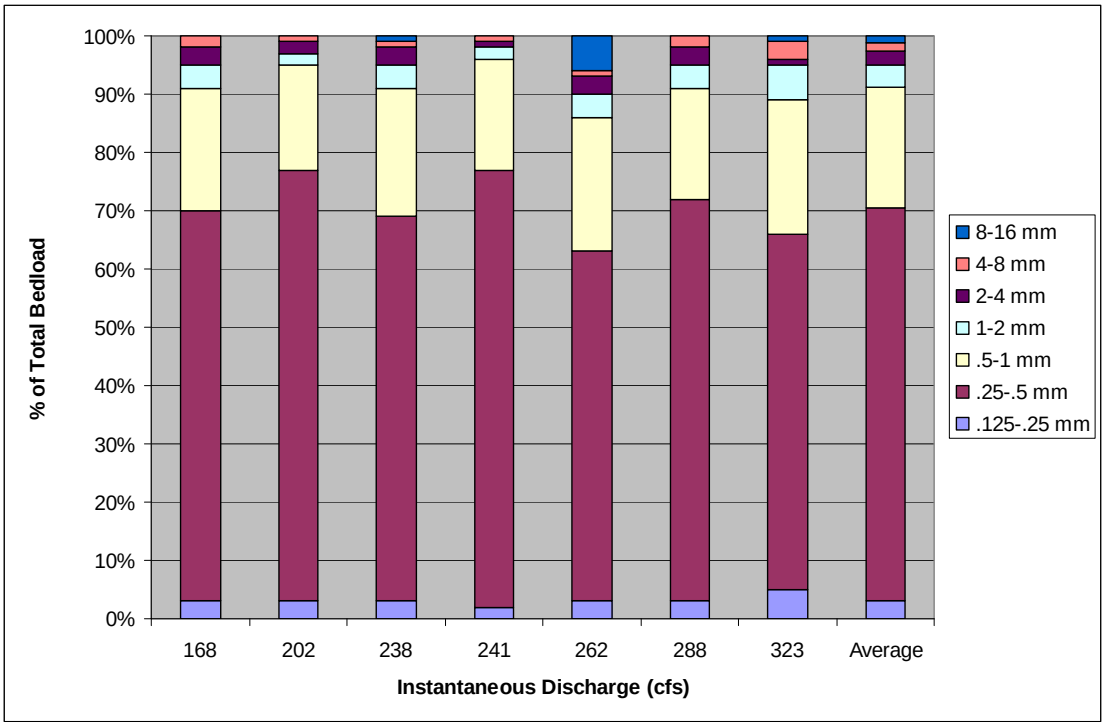

Figure 6 Observed bed load grain size data (Adapted from USGS, 2008).

Model Verification SIAM is a sediment budget model that constructs an annualized estimate of sediment balances along reaches of a river based upon the frequency and duration information of observed hydrologic and sediment source data. SIAM does not conduct sediment transport, yield, or bed change computations, and thus consequently cannot be calibrated, per se, to observed sedimentation data. Rather, the relative trends predicted by SIAM can be compared to observed data to check the annualized sediment budgets against observed river stability, incision and deposition patterns. The process of model checking was conducted in a manner similar to calibration by tuning model parameters such that the model output and estimates of sediment volume going through the system best match observed trends in river sediment dynamics. This process is further described below.

Over the life span of the Boardman and Brown Bridge dams, sediment has accumulated within the impoundments. Given the accumulation of organic matter, along with sediment in these deposits, the volume of these deposits represents an upper limit on total sediment accumulation since the impoundments were constructed. The volume of these deposits was estimated to provide a check against the sediment budget estimates from SIAM. The estimate for Boardman Pond was developed by comparing pond volume and elevation data from a historic map to current bathymetric data collected for the project (Figure 7) and computing the change in storage capacity. Historic data were not available for Brown Bridge Pond. Consequently, the results of longitudinal and cross section surveys, paired with aerial imagery analysis, were used to estimate the extent and volume of the sediment delta in the pond.

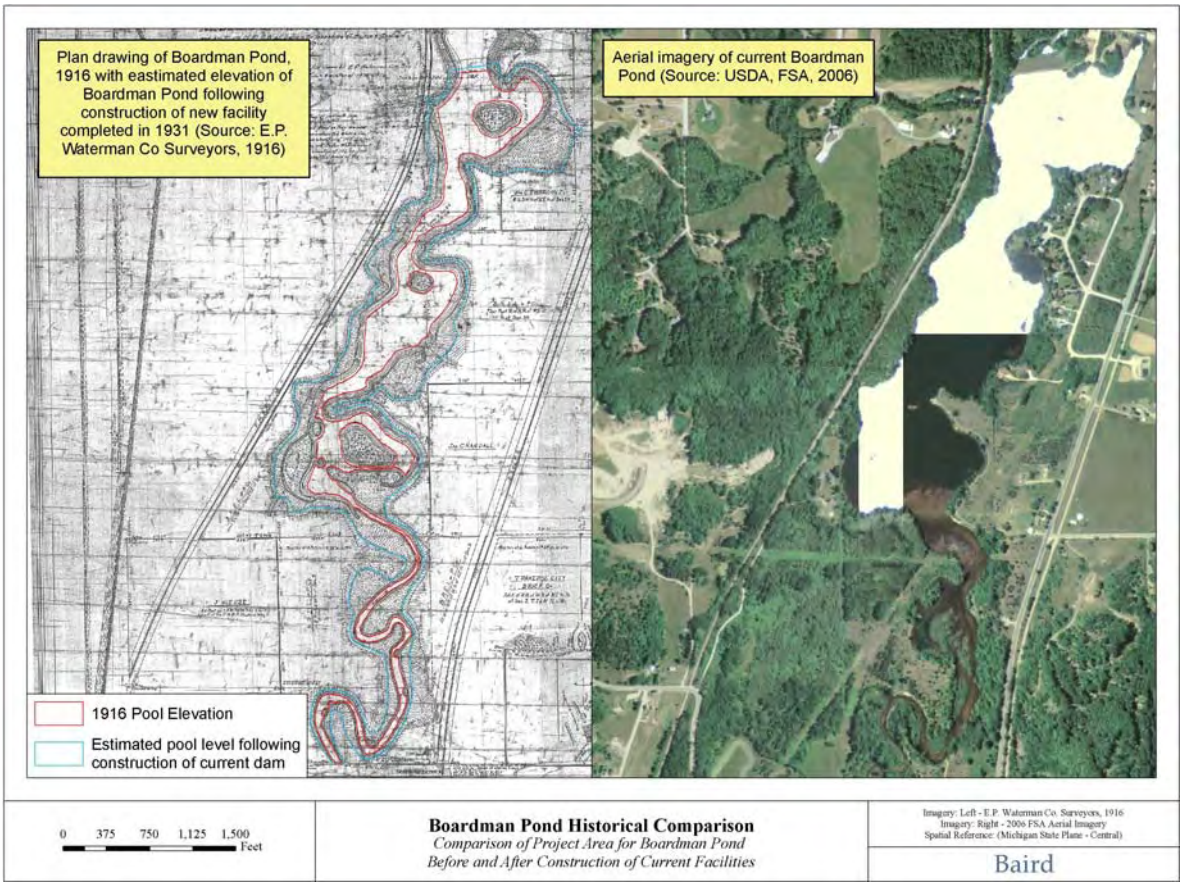

Figure 7 Comparison of historical drawings of Boardman Pond to current aerial imagery.

The sediment volumes were estimated for both Boardman Pond and Brown Bridge Pond and converted to mass using a bulk density of 1.8 Mg/m^3(this value was selected based upon published literature values for reservoir sediments in similar regions). These values were converted to equivalent depths across the entire impoundment areas, shown in Table 2. This conversion allows for direct comparison to the results of the SIAM model. The volumes of sediment were also converted to basin scale denudation rates for the watershed areas upstream of each dam. These were corrected to account for the linear arrangement of the dams and dam history. The denudation rates were similar for the two impoundments and consistent with reviewed literature (Riedel, et. al., in review).

Table 2 Estimation of sediment accumulation in Brown Bridge and Boardman Ponds.

Impoundment	Volume of Sediment *ac-ft*	Mass of Sediment *tons*	Sedimentation *in/yr*	Denudation Rate *mm/yr*
Brown Bridge	1,240	3,027,000	0.5	0.05
Boardman	710	1,700,000	1.6	0.04

The base SIAM run used a default washload threshold diameter of 0.125 mm, very fine sand. With the base run of the model, the results were predicting widespread sediment deficits in Boardman River including a very large deficit below Brown Bridge Dam. These results suggested the Boardman River would likely be undergoing widespread channel incision, yet field reconnaissance and inspections of old bridge footings, flood plain trees, and hydraulic structures indicated the riverbed is stable and actively connected to its floodplain. The following modifications were made to tune the SIAM model such that the results best matched the observed conditions in the Boardman River and the three impoundments:

1. Washload maximum diameter for sediment reach C, below Brown Bridge Dam, was increased to 2 mm, very coarse sand, to reduce the sediment deficit prediction.
2. Washload maximum diameter for the three dams in the model was reduced to make it impossible for larger classes of sediments to pass through the dams.
3. SIAM runs were conducted with maximum washload diameter for river reaches of 0.25 mm, 0.5 mm, and 1.0 mm to represent the range of sediment size classes that are in the threshold range for suspension yet, also a significant fraction of bed material (Figure 4).

RESULTS

The results from SIAM are reported in annualized sediment balance values, by particle size and source, for each sediment reach. We converted these values to equivalent depths of incision or deposition based upon the length and average width of each reach and an assumed sediment bulk density of 1.8 Mg/m^3 to remove effects of scale. Figure 8 shows the results of the three different scenarios. The 0.25 mm washload threshold scenario had the most imbalance of sediment across the reaches and indicated widespread supply deficits along the Boardman River; these were equivalent to sediment volume from channel scour and bed incision on the order of 5 to 15 cm/year (2 to 6 in/yr). As the size class for washload was increased to 0.5 mm and 1 mm, the predicted supply deficits for the reaches declined and most were within 5 cm/yr (2 in/yr) All scenarios showed a –13 cm/yr (5 in/yr) sediment shortage in the Boardman River below Brown Bridge Dam. The sedimentation results from the 0.5 mm washload scenarios for Brown Bridge (sediment reach B) and Boardman River (sediment reach F) best compare to observed field conditions and sedimentation rates reported in Table 2.

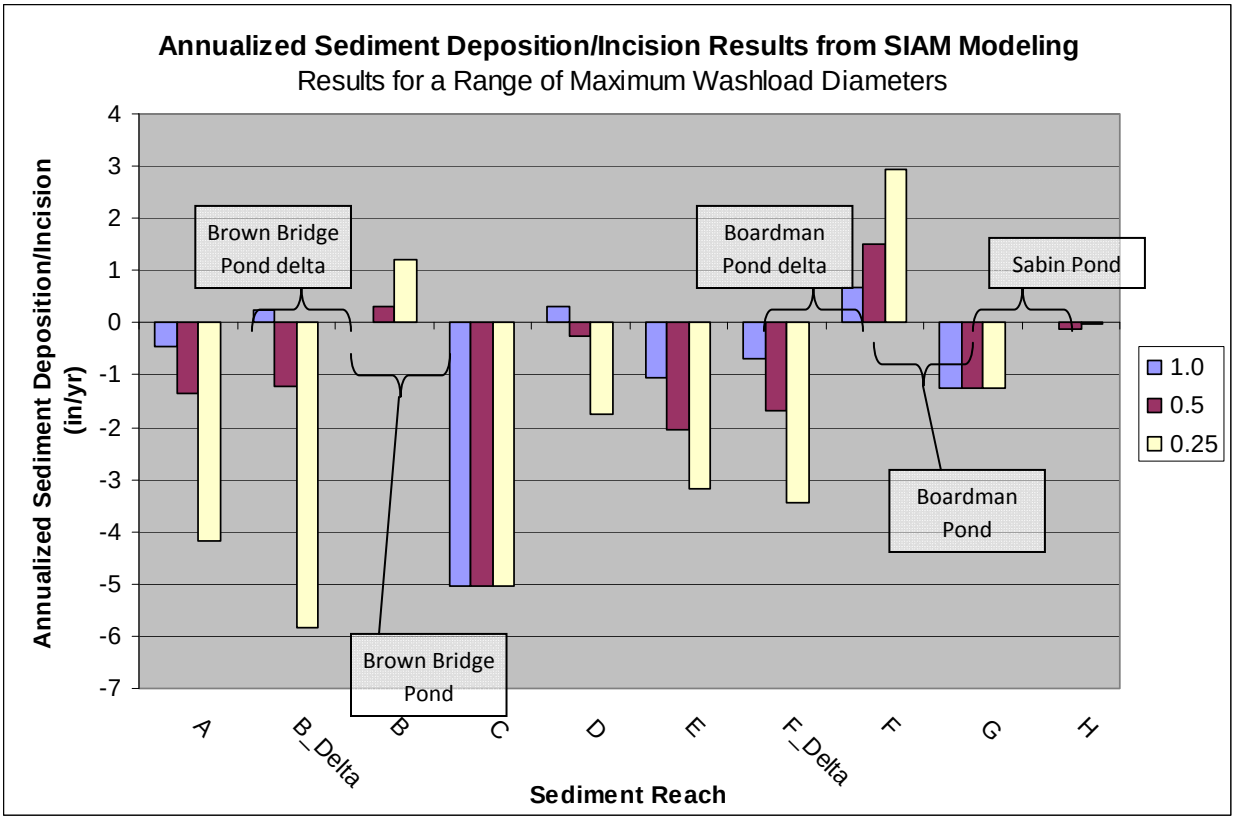

Figure 8 Results of SIAM modeling on Boardman River. Different colored bars represent different maximum washload diameter settings in SIAM.

Results showing general tendencies of each reach within the study area are shown in Table 3. Reaches D and E between Brown Bridge Dam and Boardman Pond have several large tributaries adding additional sediment supply to the river, which is eventually deposited further downstream in Boardman Pond. Although these reaches have this sediment supply coming in, the longitudinal profile of reaches D and E is much steeper, resulting in a higher sediment transport capacity relative to the supply, which results in a deficit within these reaches.

Table 3 Summary of results by reach based on SIAM modeling and field observations.

	Model Results Summary by Reach
A	Stable
B_Delta	Deficit
B	Accumulation
C	Deficit
D	Stable
E	Deficit
F_Delta	Deficit
F	Accumulation
G	Stable
H	Stable

DISCUSSION

To interpret the results shown in Figure 8, it is helpful to identify a known stable section of the river to use as a reference condition and compare each sediment reach to that. Based on field observations and USGS gage records, Reach A, upstream of Brown Bridge Pond, is stable with no evidence of channel incision or deposition at the gage location. As the results for the SIAM model predicted a sediment deficit for this sediment reach, this shortage should be considered within the natural range of variability for a dynamically stable river. The results using 0.25 mm and 0.5 mm maximum washload values best represented the observed sedimentation within the impoundments.

The results for the impoundment for Sabin Dam, Reach G, show a sediment deficit, although in reality, the impoundment acts as a sediment sink. This is most likely due to the mechanics of the SIAM model, which calculates data by reach based on a sediment balance. Because the Sabin impoundment is located directly downstream of the Boardman Dam, the model predicts most sediments to be trapped within Boardman Pond, so to balance, estimates a deficit in Sabin

The SIAM model shows a sediment deficit directly downstream of Brown Bridge Dam for all washload maximum scenarios modeled due to the sediment trapping efficiency of the structure. Field observations and historic USGS gage records downstream of this dam show that this section of the river is stable; so although this is a sediment starved section of river, the bed is well armoured and stable.

The results of the SIAM model for the delta on Brown Bridge pond suggest that this area may be subject to incision and scour, confirmed by field observations of the impoundment. The impoundment, as modeled and currently operated, was drawn-down 17 feet (ECT, 2007). The river had built a prograding delta in the impoundment, building up coarser sediments on the upstream end of the delta during low-flow conditions and re-mobilizing and depositing into deeper sections of the impoundment during high-flow events. With the dewatering and lowering of pond levels, the river has been re-mobilizing these sediments.

Within the context of these results, most areas of the river within the study reach are shown to be relatively stable based on the SIAM model and field observations. Most results showed less than 2 inches of incision or deposition in any given year, which are within the range of the natural river system based on upstream observations. The results of SIAM also showed that sediment sources from tributaries increased sediment supply downstream. Increases in bed slope from reaches D to E, where several larger tributaries join the Boardman, result in increased transport capacity relative to supply which translates to larger sediment deficits.

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