

2019

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Recommended Citation

Pan, F.; Choi, W. A Conceptual Modeling Framework for Hydrologic Ecosystem Services. *Hydrology* 2019, 6, 14. <https://doi.org/10.3390/hydrology6010014>

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1 Article

2 A Conceptual Modeling Framework for Hydrologic 3 Ecosystem Services

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7 **Abstract:** Ecosystem services (ES) help people understand and deal with current environmental
8 situations and problems, and ES-related research has been increasing recently. However, the
9 quantitative evaluations of ES that can be easily understood by decision makers are still in
10 development. Specifically, new methods are needed for hydrologic ES with the requirements of
11 spatially and temporally explicit specification of parameters related to climate, geology, land cover,
12 soil, and topography. This paper presents a conceptual modeling framework that aims to convert
13 hydrologic information to hydrologic ES in fine temporal resolutions by developing a conceptual
14 connection of three modules, data development, hydrologic and ES modeling, and results analysis.
15 Then the framework was applied to a study basin to demonstrate the importance of hydrologic ES
16 in fine temporal resolutions. Results of water provision ES, flood control ES, and sediment
17 regulation ES were produced at fine temporal resolutions in the framework, which indicates that
18 more timely and relevant policy suggestions can be provided to decision makers. The framework
19 and the methodology are applicable for watersheds of varied sizes and can serve as a template for
20 future coupling of different environmental models.

21 **Keywords:** Conceptual framework; Hydrologic modeling; Ecosystem services modeling;
22 Hydrological ecosystem service
23

24 1. Introduction

25 Human beings benefit enormously from the functions of ecosystems at various scales, for
26 example provision of food and resources, climate regulation, and recreational amenities [1]. Such
27 benefits human beings obtain from ecosystems are referred to as ecosystem services (ES) [2].
28 Although studies have been conducted to identify and value ES over the decades, the development
29 of assessment tools such as ES simulation models is still new [3]. Without quantitative evaluations of
30 the actual benefits that can be obtained from ecosystems, the importance of these services does not
31 draw adequate attention from decision makers [4].

32 Hydrologic ES, a subset of terrestrial ES related to water, are affected by complex interactions of
33 many environmental factors and require robust understanding and skills for prediction and
34 assessment [5]. Hydrologic models can simulate spatially and temporally explicit hydrologic
35 processes, capture the heterogeneities in hydrologic and meteorological parameters, and enhance
36 understanding and prediction of hydrologic processes [6]. However, most hydrologic models are not
37 designed to include functions that convert hydrologic results to the ES as easily understood by
38 decision makers [5]. On the other hand, ES models are still under development, and hydrologic ES
39 simulation is limited [5].

40 ES models and related quantitative research that have been built and conducted are limited in
41 several ways. For example, the two ES models that have been mostly applied, Integrated Valuation
42 of Ecosystem Services and Tradeoffs (InVEST) [7] and Artificial Intelligence for Ecosystem Services
43 (ARIES) [8], are comprehensive ES models that cover many kinds and aspects of ES. However, neither

44 of these two models uses temporally explicit methods to model the hydrologic ES, nor can they
45 generate temporally explicit results. More importantly, temporal scales and resolution issues with ES
46 modeling have not been studied in detail. The complex hierarchical organization of natural processes
47 and heterogeneity across time and space make the scale of ecological research very important [9].
48 Furthermore, the beneficiaries of natural ES and their observation systems are in different spatial and
49 temporal scales [10]. Most ecological functions are highly dynamic and non-linear across space and
50 time; however, such temporal non-linearity has been ignored by previous studies without
51 considering corresponding temporal scales to simulate the non-linearity of ES [11].

52 Combining ES and hydrologic models can improve them both, which would effectively
53 accelerate the ES modeling processes that need fine resolutions. Studies have been conducted to
54 couple different types of hydrologic and ES models for hydrologic ES [12-13]. To achieve the goal of
55 converting hydrologic information to ES with fine resolutions, we designed a conceptual modeling
56 framework in this paper, including a data development function, a modeling function with a
57 hydrologic model and an ES model, and a results analysis function. With this framework, we
58 established procedures for hydrologic ES data preparation, simulation, and analysis supported by
59 national geospatial data products. This framework could help decision makers and even the general
60 public understand hydrologic ES. The framework was applied to a catchment with substantial urban
61 land covers. In this paper, we evaluated three hydrologic ES variables at finer temporal resolutions
62 than previous studies.

63 The first hydrologic ES variable is water provision ES. Limited studies have been conducted with
64 a focus on water-related ES [14-18], with only a few of them on a seasonal or monthly basis [19-20].
65 Compared to Notter et al. [19], who used monthly hydrologic results to calculate the ES indices, this
66 study not only uses daily hydrologic data but produces monthly and seasonal ES indices which can
67 provide more detailed information for decision makers. Similar to Schmalz et al. [20], the seasonal ES
68 has been calculated to capture the high and low water provisions in different seasons. Furthermore,
69 this study also compares annual and monthly changes to highlight the necessity of fine temporal
70 results.

71 The second hydrologic ES variable is flood regulation ES. Because floods have short time frames,
72 annual results may not be adequate for management activities. With the ability of this framework to
73 simulate monthly and seasonal ES output, these extreme events could be captured and related
74 remedies could be designed. Unlike previous ES studies [16, 21], the flooding regulation ES simulated
75 in this study can not only predict the flooding risk per year but also pinpoint the months and seasons
76 when regulation for ES should be applied.

77 The third hydrological ES variable is sediment regulation ES. When it comes to sediment
78 retention, even if sediment yields were low in a year, they could be quite high in some months, thus
79 attention should be given to such months. Previous ES studies focused on sediment regulation with
80 annual outputs [14, 15, and 21]. In general, they tested different land-use scenarios on the study areas
81 to calculate different sediment yields for comparison and tradeoff, neither of which captures the
82 seasonal changes in sediment associated with extreme hydrologic events nor provides guidance as
83 in this study and that of Schmalz et al. [20].

84 In short, this study focused on finding the changes in hydrologic ES at fine temporal resolutions
85 compared to previous hydrologic ES studies. As mentioned earlier, ES models (e.g. InVEST) were
86 limited to the annual scale with their design and most of the studies focused on tradeoff of different
87 land use scenarios or mapping the spatial distribution of ES [4, 14, 15, and 18]. Other hydrologic
88 models (e.g. SWAT) capable of simulating hydrologic variables at fine temporal resolutions were also
89 utilized in previous studies [19-21], but only Schmalz et al. [20] conducted their study at the seasonal
90 scale and the smallest hydrologic unit in SWAT. Thus, further studies at fine temporal resolutions in
91 hydrologic ES are still needed.

92 The novelty of our work lies in developing the conceptual framework and demonstrating the
93 importance of evaluating hydrological ES at fine temporal resolutions compared to previous studies
94 [14-21]. The results of the framework showed that hydrologic ES were temporally sensitive, and with

95 this conceptual modeling framework, these fine temporal changes could be captured and relevant
 96 management plans and policies could be made accordingly.

97 The upcoming sections of this article provide details of our framework. In Section 2, we introduce
 98 hydrological and ES models used for the framework and explain each function in the framework. We
 99 also describe data sources and the study site in Section 2. Results and discussion for each ES variable
 100 are provided in Section 3, followed by conclusions in Section 4.

101 2. Materials and Methods

102 2.1 Hydrologic model

103 The Hydrologic Simulation Program-Fortran (HSPF) [22] was employed in this study to simulate
 104 streamflow and sediment yields. HSPF is a comprehensive, physically based, semi-distributed
 105 hydrological model [23]. It has been applied to study hydrological variables such as streamflow,
 106 sediment yield, and non-point source pollution in many projects conducted around the world [e.g.
 107 24-28].

108 In HSPF, the study area is first divided into subbasins according to topography as each subbasin
 109 is the smallest catchment that contains a stream channel with no branch [23]. Each subbasin is
 110 configured to have three basic components, namely pervious land segments (PERLND), impervious
 111 land segments (IMPLND) and stream channel/reservoir (RCHRES) [23]. Land surface processes are
 112 simulated for PERLND and IMPLND first. Simulation results from PERLND and IMPLND are then
 113 passed to RCHRES for channel/reservoir or hydraulic processes simulation. With land use/cover,
 114 imperviousness, climate, reaches and subbasin data, the hydrologic modeling function will be set up.
 115 The PERLND, IMPLND, and RCHRES are assigned based on subbasin delineation, land use/cover
 116 types, weather stations, and the ratio of perviousness and imperviousness for each land use/cover
 117 type. The geometric and hydraulic properties of an RCHRES are represented in HSPF by an FTABLE,
 118 which describes the relationships between stage, surface area, volume, and discharge for the reach
 119 segment.

120 The hydrologic processes of the model are based on the water-balance equation (Eq. 1).

$$121 \quad SMC_t = SMC_{t-1} + \sum_{t=1}^T (P_t - R_t - ET_t - G_t) \quad (1)$$

122 where SMC is the soil moisture content, t is time in days, T is the total days, P is the daily amounts of
 123 precipitation, R is the runoff, ET is the actual evapotranspiration, and G is the deep groundwater
 124 (percolation). All of the units are in mm.

125 The data products we used for HSPF are listed in Table 1.

126 Table 1 Summary of data sets used for hydrological modeling

Data sets	Spatial resolution	Source
Digital elevation data	30m	US Geological Survey (USGS) [29]
Land cover map	30m	National Land Cover Database (NLCD) [30]
Climate data	8 km	University of Wisconsin-Madison [31]
Streamflow and sediments yield data	N/A	USGS [32]

127
 128 The model parameters were calibrated against the measured streamflow data for the period
 129 1986-1995 and were subsequently validated for the period 1996-2005 in the previous study [21]. The
 130 calibration period was selected considering the timing of the NLCD data and the availability of
 131 streamflow data. The comparison with the measured streamflow was conducted in terms of relative
 132 error (RE) and the Nash-Sutcliffe Efficiency (NSE). Sediment data have very limited availability, thus
 133 available daily numbers were averaged to monthly ones and compared with.

134 2.2 ES model and methods

135 To evaluate ES, quantitative methods created by Logsdon and Chaubey [21] were used with
 136 modification to configure the fine temporal resolution requirement. In this paper, the time step was
 137 a day, and the results were analyzed at both monthly and seasonally to illustrate the change of water
 138 demand throughout the year.

139 2.2.1 Water provision ES

140 The water provision ES was calculated as the index of water provisioning (WPI) (Eq. 2).

$$141 \quad WPI_t = \frac{MF_t/MF_{EF}}{MF_t/MF_{EF} + qne_t/n_t} \quad (2)$$

142 where WPI is water provision index, MF is the mean flow (m^3/s), MF_{EF} is the long-term environmental
 143 flow requirement (m^3/s), qne is the number of times the flow is less than environmental flow
 144 requirements in the time step, and n is the total number of units in the time step.

145 The WPI equation adopted in this study does not include water quality index (due to the data
 146 scarcity) unlike the original equation developed by Logsdon and Chaubey [21]. The WPI ranges from
 147 0 to 1 where 0 indicates that provision of water quantity is not met at all, and 1 indicates that provision
 148 of water quantity is met for the entire period of time. Base on Tennant [33], 30% of average flow for
 149 each month was used as MF_{EF} to sustain good aquatic ecosystem functioning. The qne value was
 150 calculated on a daily basis.

151 We then grouped individual monthly WPI numbers into three categories with respect to the
 152 mean and standard deviation to examine the distribution of monthly WPI numbers. Category A is
 153 for those above the mean by one standard deviation or more, category B is for those within one
 154 standard deviation from the mean, and category C is for those below the mean by one standard
 155 deviation or more.

156 2.2.2 Flood regulation ES

157 The flood regulation ES was calculated as the flood regulation index (FRI). FRI incorporates three
 158 flood characteristics, quantity, duration, and extent of the flooding [34] and is calculated according
 159 to Eq. (3).

$$160 \quad FRI = \frac{1}{\exp[w_1 \cdot (DF/DF_{LT}) + w_2 \cdot (QF/QF_{LT}) + w_3 \cdot (FE/FE_{LT})]} \quad (3)$$

161 where DF is the duration of flood events (days), QF is the average magnitude of flooding events
 162 (m^3/s), FE is the number of flood events per month or year, w_1 , w_2 , and w_3 are user designed weights
 163 for each component of flooding (the sum of the weights is 1), and the LT subscript represents long-
 164 term (historical) data.

165 The FRI ranges from 0 to 1 with 0 representing maximum regulation needed and 1 representing
 166 no regulation needed. As discussed in the introduction section, flood regulation ES is time sensitive.
 167 With this adopted method, the FRI will be calculated for each month with daily data to highlight
 168 seasonal changes in flood events and their effects. Long-term observed streamflow data from the
 169 study area were used to determine the flood flow (calculated as the 10th percentile of the flow), which
 170 then was used to calculate the long-term values for average duration of flood events, average
 171 magnitude of flood events, and average number of flood events per year.

172 The individual monthly FRI numbers were then divided into two categories: A (FRI = 1 as no
 173 flood) and B (FRI < 1 as flood events) for further analysis.

174 2.2.3 Sediment retention ES

175 The sediment retention ES was calculated as the sediment regulation index (SRI), which is
 176 defined in Eq. (4):

$$177 \quad SRI = \exp(1 - (S/S_{max})) \quad (4)$$

178 where S is the monthly/annual erosion rate (T/ha) and S_{max} is the monthly/annual maximum allowable
179 (or natural) rate of sediment (T/ha).

180 The range of SRI is 0 to infinity. When the monthly sediment equals to or less than the allowable
181 sediment, the SRI is equal to or larger than 1, meaning no regulation is needed. If the sediment is
182 greater than the maximum allowable sediment, the ERI is less than 1, indicating that sediment
183 regulation is needed. The maximum allowable sediment load used was the area-weighted US
184 Department of Agriculture 'T' factor for tolerable soil loss [35]. It was determined to be 1.34 T/ha/year
185 and then converted to monthly data, weighted by flow data.

186 The counts of SRI by month were then grouped into three categories, A is for those above the
187 mean by one standard deviation or more, B is for those within one standard deviation from the mean,
188 and C is for those below the mean by one standard deviation or more.

189 2.3 The conceptual framework and workflow

190 The complete conceptual workflow of the framework is portrayed in figure 1. The framework
191 consists of three main functions, namely data development, modeling, and results analysis, each of
192 which is further described below.

193 In the data development function, digital elevation model (DEM) data were used to create
194 watershed boundary and stream network. Then watershed boundary, weather station map,
195 imperviousness map, land use/cover map and stream network were used to assign properties for
196 each subbasin and stream segment. At the end, all the data were input to the data model loader for
197 initializing the hydrologic model.

198 The modeling function has two components, hydrological and ES models. In this study,
199 hydrological model (HSPF) outputs were fed into the three hydrological ES models described
200 previously. In the hydrologic model, with the data from data development function, all the
201 parameters were initialized with default values and some numerical data were manually input. Then
202 the model was calibrated against the observed data by optimizing sensitive parameters, and the
203 simulations was conducted with the best combination of parameters. In the ES model, the three ES
204 were simulated with the hydrologic outputs and other manually input data.

205 In the results analysis function, the hydrologic ES results are produced as grids and then
206 aggregated to subbasin and basin scales for different research purposes. With regard to temporal
207 scales, the results are calculated in daily steps and then aggregated to monthly and annual scales for
208 different purposes. This paper presents an example of results at different temporal scales.

209 Furthermore, an impact analysis can be conducted adopting various scenarios such as climate change
210 and land use/cover change.

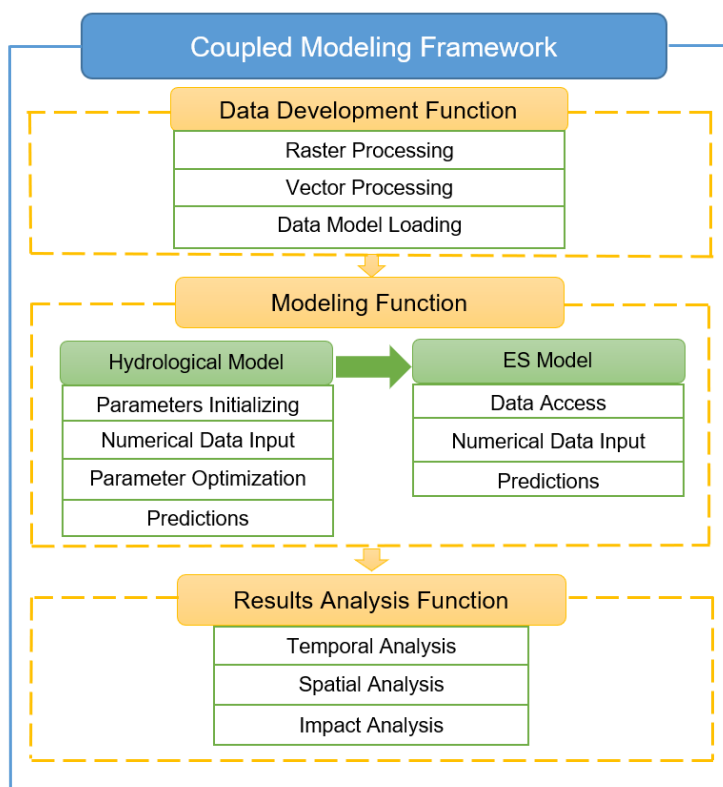
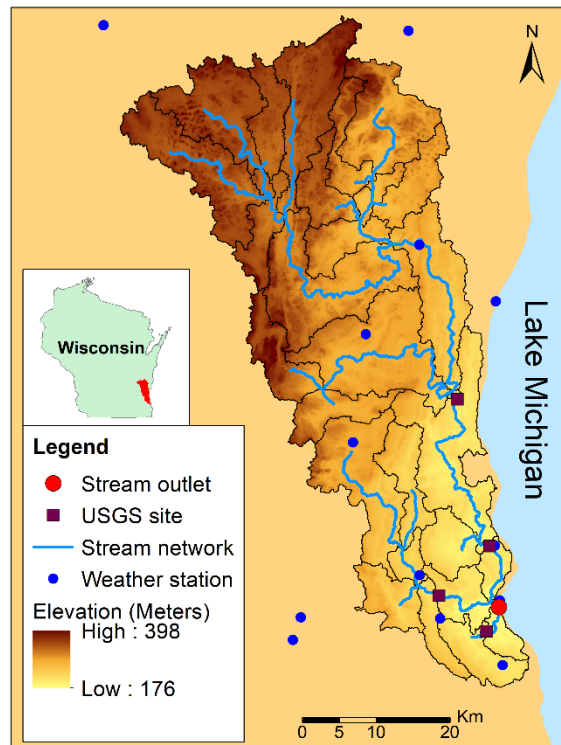


Figure 1. Workflow of the modeling framework

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213 *2.4 Study area*

214 We tested the framework for the Milwaukee River basin (Figure 2), which includes 13 cities, 32
 215 towns, and 24 villages. The total population of the basin is about 1.3 million and the basin area is
 216 about 2267 km². The southeast part, where the city of Milwaukee is located, is the most densely
 217 populated and urbanized area in the state whereas the land cover in the northern portion consists
 218 primarily of agricultural land. Across the basin, predominant land cover types include forest (11%),
 219 wetland (12%), planted/cultivated (43%), and urban (32%). The basin has topography comprised of
 220 rolling moraine over bedrock, and it slopes downward from northwest to southeast, exiting to Lake
 221 Michigan [36].



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Figure 2. Study area: Milwaukee River basin boundary, subbasins delineated for hydrological modeling, streamflow measurement sites, elevation, and stream network

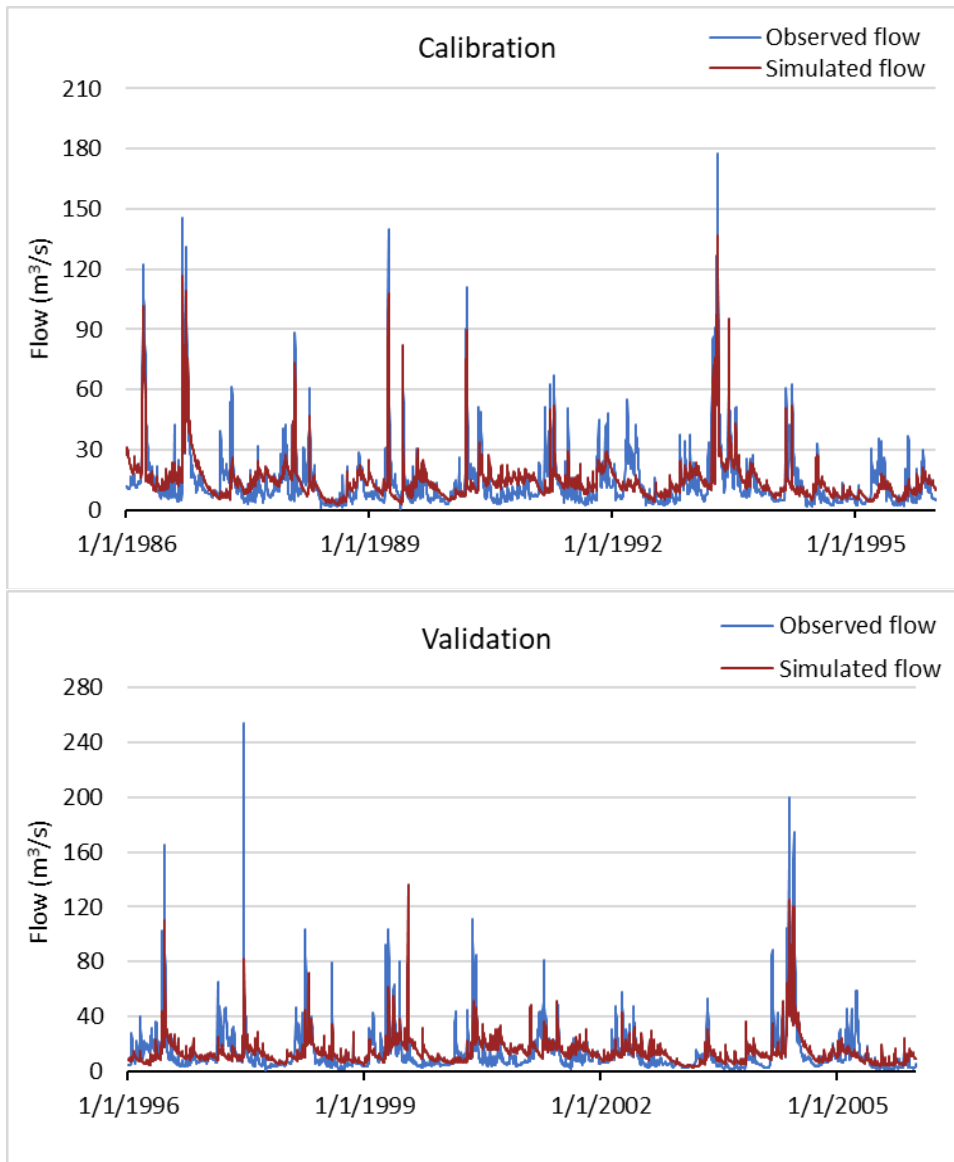
225 3. Results and Discussion

226 3.1. Hydrological modeling

227 For the calibration period, the RE was 2.13% and NSE was 0.71 at the USGS streamflow
228 measurement site (site number 04087000, the second one from north in figure 2). They were 4.87%
229 and 0.54 for the validation period, respectively. The time series of observed and simulated flow are
230 shown in Figure 3. Overall, the results of streamflow calibration and validation show good
231 performance of the HSPF model.

232 The simulated and measured total suspended solids were then compared on monthly and
233 annual bases (see Figure 4) without calibration since daily measurements were not available. The RE
234 numbers at annual and monthly scales are 3.26% and 9.57%, respectively. The comparison indicates
235 overestimation at both monthly and annual scales, whereas the monthly simulations show larger
236 overestimation.

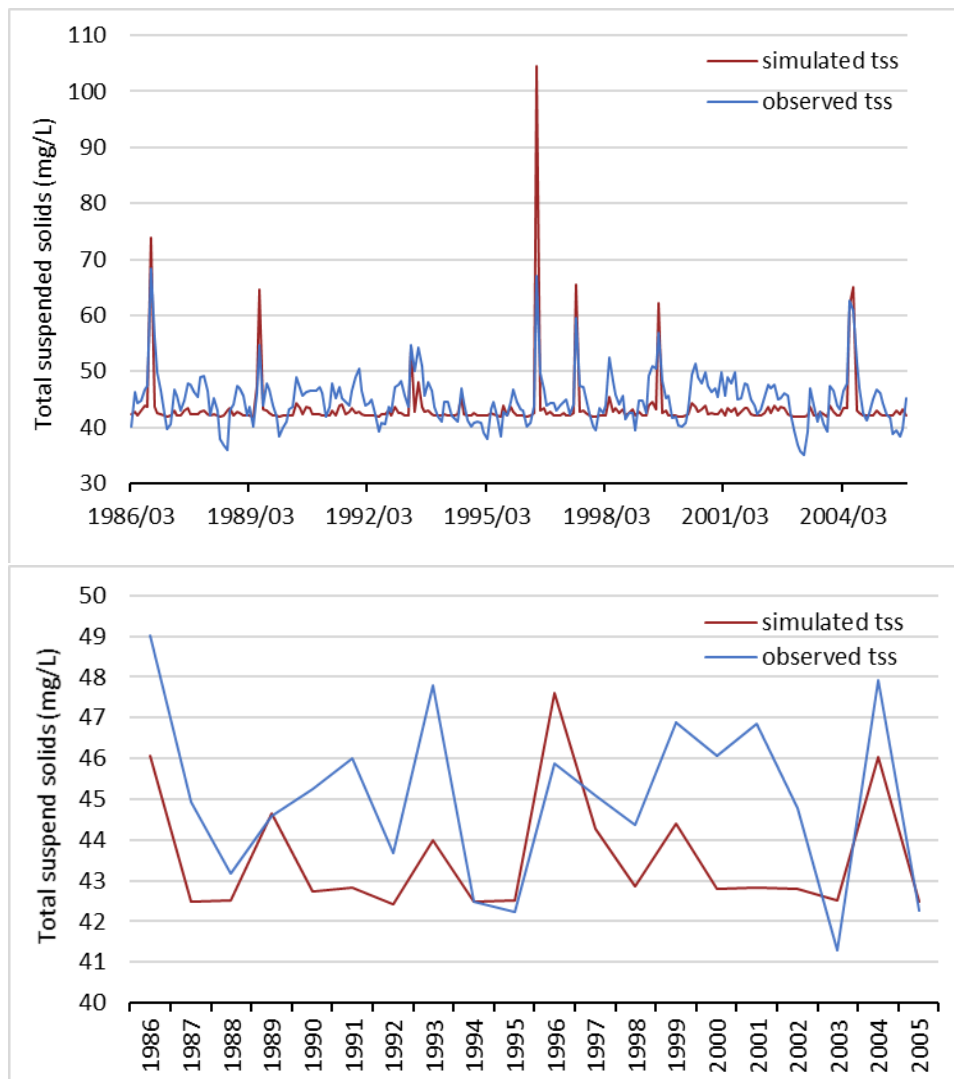
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Figure 3. Hydrologic time series for calibration and validation periods at the USGS streamflow measurement site Milwaukee River at Milwaukee, WI (04087000).



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Figure 4. Total suspended solids as monthly (top) and annual (bottom) time series between simulation and observation.

250 3.2. Ecosystem services modeling

251 3.2.1 Water provision index (WPI)

252 The WPI (Eq. (2)) was calculated both as annual and monthly time series for the entire basin
 253 (figure 5). The annual WPI ranges between 0.35 and 0.85 and reveals a slightly decreasing trend
 254 during the study period. The diminished water provision could be caused by some natural processes
 255 such as reduced precipitation, increased evaporation and/or water table depression as well as some
 256 human effects such as over-consumption of water for domestic or industrial use. The monthly WPI
 257 fluctuates wildly, between less than 0.2 and 1.0, and monthly WPI numbers below 0.2 occur more
 258 frequently in the second half.

259 We would like to further highlight some notable differences between annual and monthly
 260 results in Figure 5. For example, in years 1986 and 2004, annual WPI was very high but monthly WPI
 261 was very low in late summer of the years. The monthly WPI in the years was as low as those when
 262 annual WPI was quite low such as 1987-1988 and 2002-2003. In years 1988, 1998, and 2003, annual
 263 WPI was low but monthly WPI in late spring or early summer of the years was very high even
 264 compared to some years (such as 1986 and 2004) with high annual WPI. These findings indicate that
 265 annual WPI alone cannot provide enough or adequate information about when the shortages come.

266 The monthly WPI time series was converted to the mean monthly WPI (figure 6) to examine the
 267 seasonal variability in the study basin. Figure 6 reveals high-water provisions in spring and very low

268 water provisions in summer. Given the results at different temporal resolutions of the water
 269 provisions, the management plan for this basin could focus on low-flow seasons to keep the level of
 270 water provision stable.

271 The category counts described in section 2.2.1 for each month are provided in table 2. For
 272 category A, spring (Mar to May) has the most counts, and for category C, spring has the least counts,
 273 which indicates high water provision in spring. Category A has the least counts and Category C has
 274 the most counts in summer and early autumn (July to Oct), which indicates low provision in this
 275 season. This further demonstrates that monthly results can provide information for water provision
 276 management considering seasonal variations.
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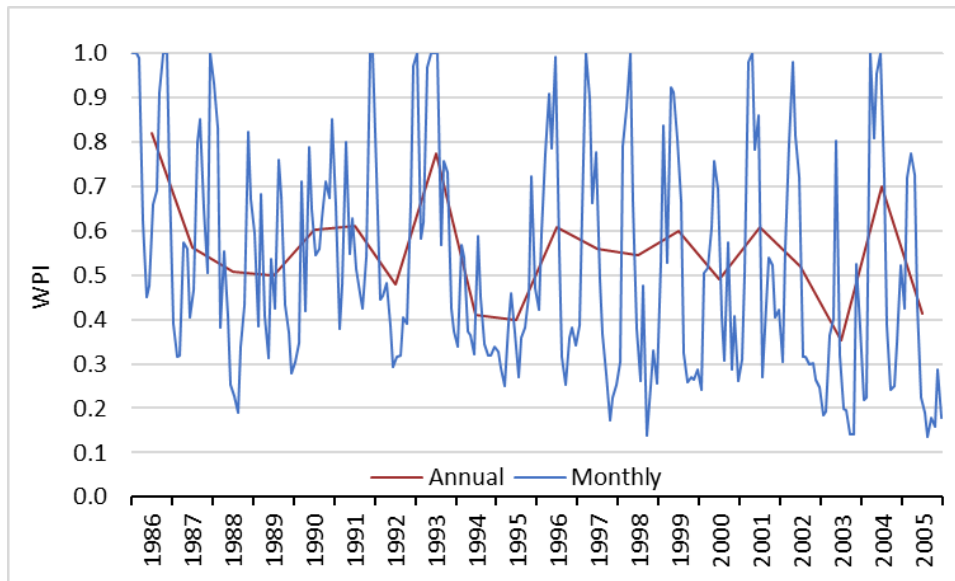


Figure 5. Annual and monthly water provision index time series

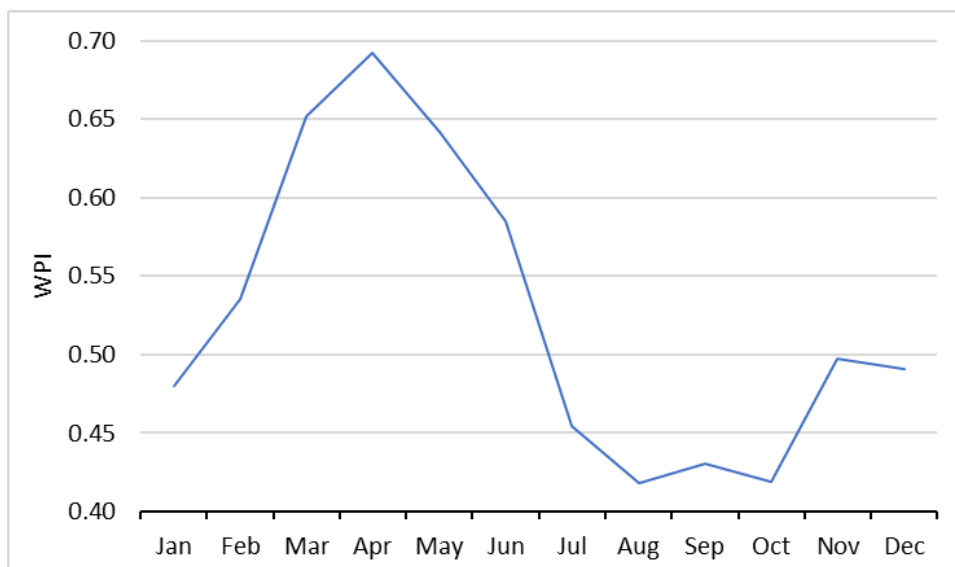


Figure 6. Mean monthly water provision index

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Table 2. Counts of monthly water provision index numbers above the mean by one standard deviation or more (A), within one standard deviation from the mean (B), and below the mean by one standard deviation or more (C)

Category	A	B	C
Month			
Jan	3	14	3

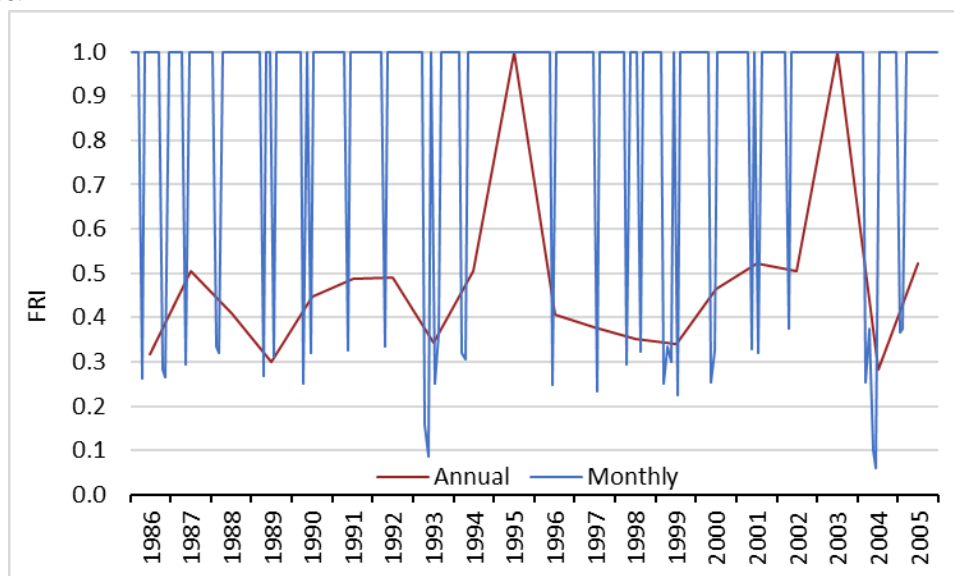
Feb	4	14	2
Mar	8	11	1
Apr	9	11	0
May	8	12	0
Jun	6	12	2
Jul	1	13	6
Aug	1	16	3
Sep	2	11	7
Oct	1	13	6
Nov	3	14	3
Dec	4	10	6

287 3.2.2 Flood regulation index (FRI)

288 The FRI (Eq. (3)) was calculated as both annual and monthly time series (figure 7), and mean
 289 monthly as well (figure 8). As mentioned before, 0 represents maximum regulation needed and 1
 290 does no regulation needed.

291 The annual FRI (figure 7) mostly hovers around 0.4-0.5, which indicates that management is
 292 needed to some extent to regulate the flood effects most of the time. However, the monthly FRI
 293 numbers are 1 most of the time and very low occasionally, which means no flood regulation is needed
 294 for most of the time. Monthly FRI shows that flood regulations were not required except for some
 295 months. Eq. 3 indicates that the magnitude and duration of flood events highly impact FRI. These
 296 findings reveal that further flood regulation will only be needed for certain months or seasons.
 297 Annual results were not adequate for the flood regulation management plans.

298 Figure 8 reveals that spring is the time when the study basin is most vulnerable to flooding, and
 299 winter is relatively safe from flooding. The category counts described in section 2.2.2 are provided in
 300 table 3 for each month. Together with figure 8, these results indicate that the study area is subject to
 301 more flood events from March to July compared to other seasons. Thus, decision makers should
 302 establish some seasonal and temporary management (e.g. moveable dams) to prevent or reduce flood
 303 duration and magnitude and such controls should be implemented for the spring and early summer
 304 in the future.



305 Figure 7. Annual and monthly flood regulation index time series
 306

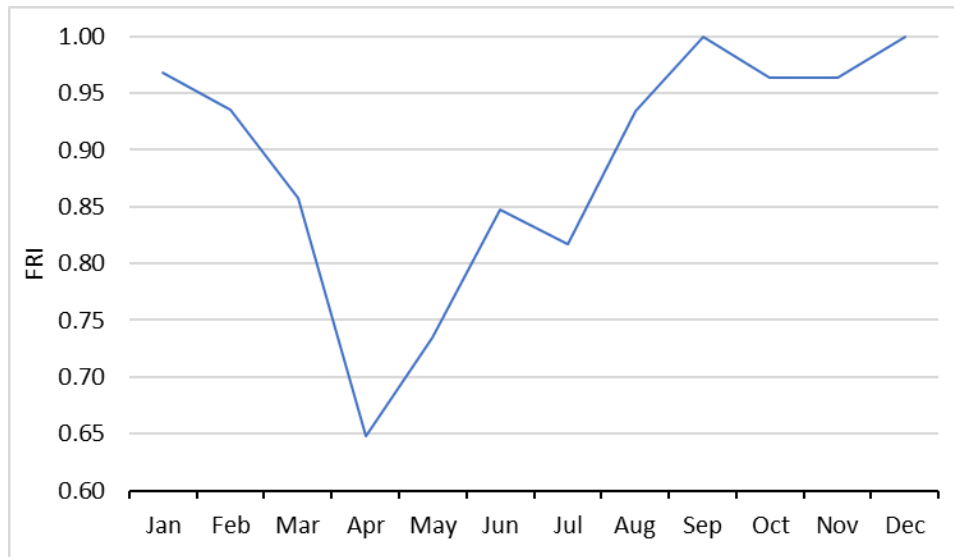


Figure 8. Mean monthly flood regulation index

Table 3. Counts of flood regulation index numbers equal to 1 (A) and less than 1 (B)

Category	A	B
Month		
Jan	19	1
Feb	18	2
Mar	16	4
Apr	10	10
May	13	7
Jun	16	4
Jul	15	5
Aug	18	2
Sep	20	0
Oct	19	1
Nov	19	1
Dec	20	0

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311 3.2.3 Sediment regulation index (SRI)

312 The monthly and annual time series of SRI are presented in figure 9 and the mean monthly SRI
313 is presented in figure 10. As shown in figure 9, the annual SRI generally fluctuates around 0.8 with a
314 fairly wide range (above 1.1 and below 0.4). Monthly SRI shows similar fluctuations with a larger
315 variability. Although some years (e.g., 1986, 1989, 1996, and 1997) have very low monthly values,
316 their annual SRI is rather high, and for the year 2004, the monthly values are very high whereas the
317 annual SRI value is low. Based on these findings, it should be noted by decision makers that, with
318 monthly results of SRI, some months of high demand of regulation would be found in low demand
319 years. It suggests that they should plan and apply sediment regulations with more detailed time steps
320 than annual.

321 Mean monthly SRI in figure 10 reveals that the SRI is lowest in June. However, spring is the
322 season with the most precipitation. This indicates that the highest sediment regulation demand did
323 not come with the largest precipitation and it also was associated with temporal soil erodibility
324 variation [37]. The counts of monthly SRI in table 4 as described in section 2.2.3 show that the further
325 the month is away from June, the fewer the counts of A are, which means less regulation is need.
326 Along with figure 10, these monthly results indicate more regulation is needed in summer than the
327 rest of the year.

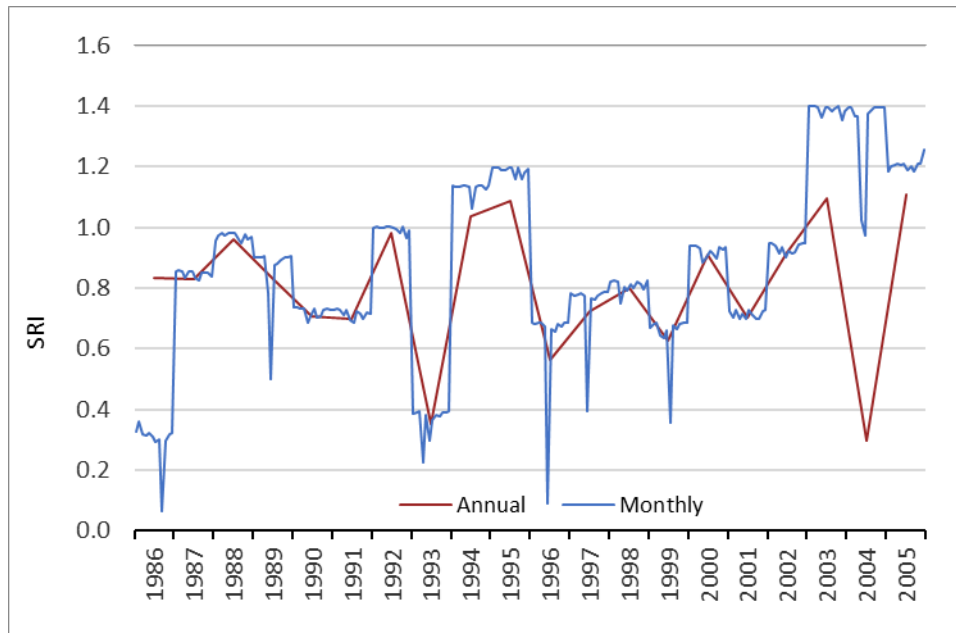


Figure 9. Annual and monthly sediment regulation index time series

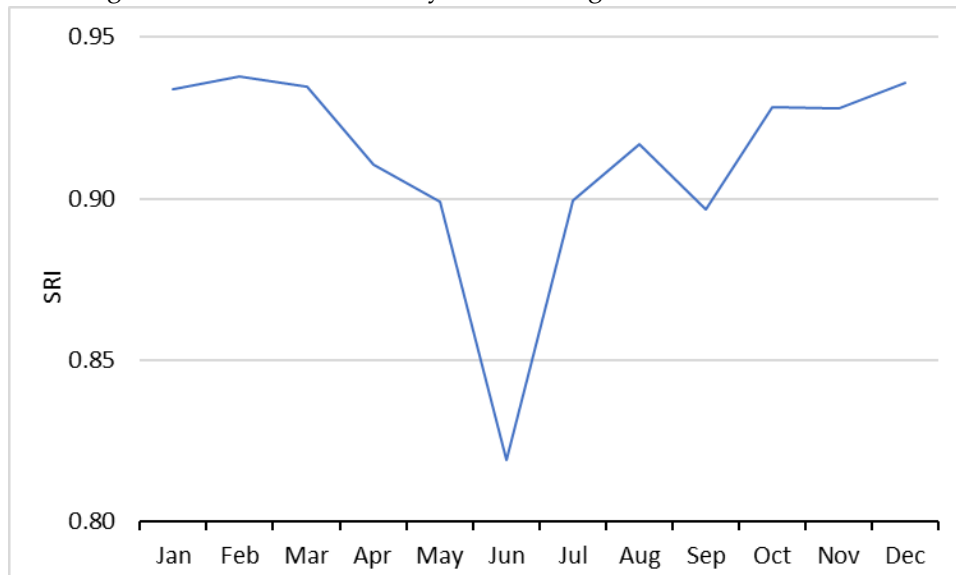


Figure 10. Mean monthly sediment regulation index

Table 4. Counts of sediment regulation index numbers above the mean by one standard deviation or more (A), within one standard deviation from the mean (B), and below the mean by one standard deviation or more (C)

Category \ Month	A	B	C
Jan	2	14	4
Feb	2	14	4
Mar	2	14	4
Apr	2	14	4
May	2	15	3
Jun	5	12	3
Jul	3	13	4
Aug	2	15	3
Sep	2	14	4

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Oct	2	14	4
Nov	2	14	4
Dec	2	14	4

336 4. Conclusions

337 In this paper, a conceptual modeling framework that can simulate ES with fine resolutions was built
338 to conduct ES studies with fine temporal resolutions. The framework includes both a hydrologic
339 model and an ES model. This framework can preprocess and access the input data efficiently and can
340 simulate hydrologic ES at the same temporal resolution as the hydrologic model used in this study.
341 With this framework, hydrologic results were converted to indices results for evaluating water
342 provision, flood control, and sediment regulation in different ways, such as a general increasing or
343 decreasing trend, detailed analysis of the changes, and seasonal changes to be used by decision
344 makers. The results of the three hydrologic ES at both annual and monthly resolutions reveal that
345 annual results alone in ES simulation and analysis for management plans is not adequate for time
346 sensitive plans and including fine temporal resolutions is necessary for some ES that are event-based
347 or have large seasonal variations.

348 The design of the framework established a strategy for integration of data development,
349 hydrologic and ES modeling, and output analysis supported by national data products for multiple
350 research purposes. The framework established in this study not only confirmed the necessity of the
351 function to study the hydrologic ES with fine temporal resolutions, but also created a workflow for
352 combining different types of ES and hydrologic models for various hydrologic ES related research.
353 With the organization of tools in a procedural framework, the processes of ES modeling are very
354 straightforward and can be used to set up new ES modeling in any basin in the U.S. for studies similar
355 to the study area in this paper. For other study areas where hydrologic research has already been
356 conducted, only ES data preparation and ES modeling execution would be needed for ES modeling.
357 Additionally, thanks to the flexibility of the framework, other hydrologic models with different
358 mechanisms, other types of ES models, and different climate or land use/cover scenarios could be
359 used in this framework.
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