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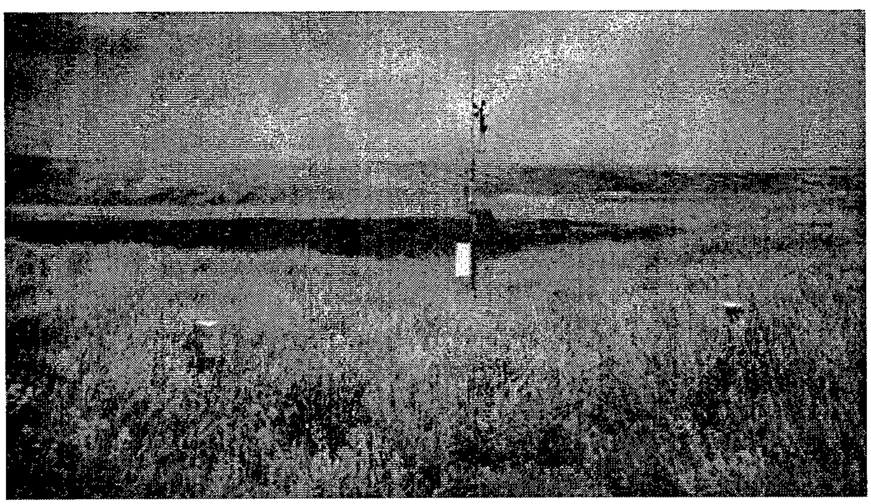
Numerical Assessment of Hydrologic Functions in Prairie Potholes

PURPOSE: This technical note outlines ongoing efforts to validate assessment models developed for the maintenance of static and dynamic surface water storage in permanent, temporary, and seasonal prairie pothole wetlands in the north-central United States.

BACKGROUND: Section 404 of the Clean Water Act (33 U.S.C.1344) directs the U.S. Army Corps of Engineers, in cooperation with the U.S. Environmental Protection Agency (EPA), to administer a regulatory program for permitting the discharge of dredged or fill material in waters of the United States. Waters of the United States, by definition, include wetlands and other special aquatic sites. Applications for permits to discharge dredged or fill material in waters of the United States undergo a public interest review that includes assessing the impact of the proposed project on wetland functions. Results of the functional assessment, as well as other factors related to the public interest, are considered in the decision to issue or deny the permit to discharge.

The hydrogeomorphic (HGM) approach (Smith et al. 1995) is a tool for assessing the impact of proposed projects on wetland functions. Under this approach, assessment models are used to calculate a functional capacity index that measures the ability of a specific wetland to perform functions relative to similar wetlands in the region (Brinson 1993). The indices represent a balance between the limited time and resources typically available for the assessment of wetland functions during the permit review process, and the need for scientific accuracy in detecting functional changes within a wetland system.



Prairie pothole with monitoring instrumentation

In developing a regional guidebook for a wetland subclass, conceptual assessment models are developed based on scientific judgement. These models are subsequently refined and calibrated using data collected at reference wetland sites that cover a range of possible conditions and exhibit different levels of function. As more data are collected from the reference sites, assessment models will be refined further.

The most important functions of prairie pothole wetlands relate to providing a sustainable water supply for the region by means of static surface water storage and dynamic surface water storage.

A qualitative ranking system for both of these functions has been proposed in Lee et al. (1997). The ranking system for the maintenance of the static surface water storage in the wetlands is intended to provide a measure of the wetland's role in the sustainability of the area's surface and groundwater supply. The ranking system for the maintenance of the dynamic surface water storage intends to provide a measure of the wetland's ability to provide water above the temporary zone. Dynamic storage is important in maintaining subsurface recharge and a stable vegetation zone above the more consistent saturated regions.

The purpose of this study is to aid in ongoing calibration of model variables and assessment models through the use of numerical hydrologic models. Models can be used to test various ranking systems quickly and easily without disturbing real wetland systems.

METHODS: A methodology similar to the WETSIM 1.0 and 2.0 models described in Poiani and Johnson (1993) and Poiani et al. (1996), respectively, was used to simulate the hydrologic system. Specifically, a surface/subsurface hydrologic model was created for wetland P1 in the Cottonwood Lake area, North Dakota. Then, hypothetical wetland systems were created according to the variable conditions described in the revised operational draft guidebook for the static and dynamic surface water storage functions. The model was used to assess the quantitative relationships of the current FCI scores and the relative sources of surface and groundwater fluxes to wetland P1. Previous models of the site focused on the surface water component with inclusion of the groundwater component through a regression equation or as a fraction of the infiltration. Our approach was to link surface water, groundwater, and wetland zone mass-balance models to simulate the entire hydrologic budget from 1981 to 1988. Simulation of the overland flow component is analogous to the WETSIM 2.0 model. This approach utilizes the erosion productivity impact calculator (EPIC) model to simulate surface water movement, infiltration, and snowmelt. MODFLOW was used to simulate the groundwater flow system, and the wetland mass-balance routines were included as MODFLOW modules.

RESULTS

Calibration Simulation

The simulated wetland stages are in general agreement with the observed values, with the exception of the large runoff event in 1987. The differences could be due to an inaccurate rating curve at larger stages. The model was used to calculate the surface and groundwater fluxes to wetland P1. The model indicates that surface water flow produces short-duration, large-magnitude inflows, typically associated with spring thaws. The groundwater fluxes are much smaller in magnitude, with net inflows typically occurring in the spring and late fall, and early winter months. Net groundwater discharges are typically occurring in late winter, early spring, and the summer months. This type of behavior is similar to results of Parkhurst et al. (1998), but their results indicated that dual groundwater reversals occurred in only 3 of the 6 years under study.

V_{source} Indicator Assessment

Table 1 shows the results for the V_{source} simulations. The mean simulated ponded area, normalized area, and the associated FCI are given for the static surface water storage index. The simulated scores are identical for all values of the V_{source} variable, indicating that the FCI scoring algorithm

Table 1
Simulation Results for the V_{source} Variable

	Static Surface Water Storage			Dynamic Surface Water Storage		
V_{source}	Mean Simulated Area (m^2)	Normalized Area	SSWS FCI	Days Stage Above Mean Area	Normalized Time	DSWS FCI
1.00	22850	1.00	1.00	1470	1.00	1.00
0.75	22391	0.98	0.98	1430	0.97	0.97
0.50	21915	0.96	0.96	1320	0.90	0.90
0.10	21418	0.94	0.92	1170	0.80	0.80
0.00	20890	0.91	0.91	1020	0.69	0.69

is correctly accounting for the V_{source} variable. The simulated number of days that the ponded water was above the mean level, the normalized time, and the dynamic surface water storage FCI are given in Table 1. Again, the simulated score is identical to the FCI, indicating that the FCI scoring algorithm is correctly accounting for the V_{source} variable.

V_{out} Indicator Assessment

Table 2 shows the results for the V_{out} simulations. The FCI scores for the surface water storage index do not agree with the hydrologic simulations. The simulations indicate that the FCI is overly sensitive to the V_{out} variable for V_{out} values ranging between 0.25 and 0.75. The model shows a sharp response to the V_{out} parameter at 0.10, which is the point at which the outlet is at the elevation of the bottom of the wetland. Therefore, the FCI scoring algorithm may need to be adjusted such that the FCI produces a more gradually decreasing function of V_{out} from 1.0 to 0.25, then a step function to a FCI value of 0.0 at V_{out} equal to 0.1. The hydrologic model is in general agreement with the current FCI for the dynamic surface water storage index. The only discrepancy occurs at a V_{out} value of 0.5. This discrepancy is primarily due to the sharp decrease to 0.0 at a V_{out} value of 0.5, while the associated difference in the measurement condition between V_{out} of 0.75 and 0.5 does not indicate any real difference in the wetland conditions. This discrepancy would be corrected

Table 2
Simulation Results for the V_{out} Variable*

	Static Surface Water Storage			Dynamic Surface Water Storage		
V_{out}	Mean Simulated Area (m^2)	Normalized Area	SSWS FCI	Days Stage Above Mean Area	Normalized Time	DSWS FCI
1.00	22850	1.00	1.00	1470	1.00	1.00
0.75	22277	0.97	0.87	1460	0.99	0.92
0.50	22277	0.97	0.71	1460	0.99	0.00
0.25	19723	0.86	0.50	0	0.00	0.00
0.10	0	0.00	0.32	0	0.00	0.00
0.00	0	0.00	0.00	0	0.00	0.00

* The greyed areas note differences between the FCI score and the simulated score in excess of 10 percent.

by changing the FCI scoring algorithm such that the dynamic surface water storage FCI is equal to zero if V_{out} is less than (rather than less than or equal to) 0.5.

V_{subout} Indicator Assessment

Simulation results for the V_{subout} variable are shown in Table 3. The hydrologic model is in general agreement with the current FCI scoring algorithm for the static surface water index. The differences are greatest for the smaller values of V_{out}, with the largest difference being 7 percent for a V_{subout} value of 0.0. In general, the static surface water storage FCI is correctly accounting for the V_{subout} variable. Although the V_{subout} variable is not included in the dynamic surface water storage scoring algorithm, results of the hydrologic simulations indicate that this index is highly dependent on this variable.

Table 3
Simulation Results for the V_{subout} Variable

	Static Surface Water Storage			Dynamic Surface Water Storage		
V_{subout}	Mean Simulated Area (m^2)	Normalized Area	SSWS FCI	Days Stage Above Mean Area	Normalized Time	DSWS FCI
1.00	22850	1.00	1.00	1470	1.00	n/a
0.75	21510	0.94	0.98	1070	0.73	n/a
0.50	21886	0.96	0.96	1040	0.71	n/a
0.25	21553	0.94	0.94	1040	0.71	n/a
0.10	19818	0.87	0.92	530	0.36	n/a
0.00	19460	0.85	0.91	470	0.32	n/a

V_{pore} Indicator Assessment

Simulation results for the V_{pore} variable are shown in Table 4. The hydrologic model is not in agreement with the surface or dynamic surface water storage FCI's. The V_{pore} variable describes the infiltration capacity of the surface soils within the watershed. Decreasing the infiltration capacity increases the overland flow, yet decreases the recharge to the regional groundwater system. The simulation results indicate that decreased infiltration provides significantly more ponded water for the wetland system, but this is not indicated in either FCI scoring algorithm. The results indicate

Table 4
Simulation Results for the V_{pore} Variable*

	Static Surface Water Storage			Dynamic Surface Water Storage		
V_{pore}	Mean Simulated Area (m^2)	Normalized Area	SSWS FCI	Days Stage Above Mean Area	Normalized Time	DSWS FCI
1.00	22850	1.00	1.00	1470	1.00	1.00
0.50	21510	1.03	0.96	1640	1.12	0.92
0.10	21886	1.14	0.92	2020	1.37	0.85
0.00	21553	1.40	0.91	2660	1.81	0.83

* The greyed areas note differences between the FCI score and the simulated score in excess of 10 percent.

that both scoring algorithms need to be adjusted to account for the increasing trend in wetland water supply with decreasing V_{pore} values.

V_{upuse} Indicator Assessment

Simulation results for the V_{upuse} variable are shown in Table 5. The simulated results do not agree with either FCI score. The simulations show an upward trend in the available ponded water as the land use conditions change according to the V_{upuse} definitions. The land use changes decrease the infiltration, which provides more overland flow to the wetland. The static and dynamic surface water storage FCIs should be changed to reflect this type of system response.

Table 5
Simulation Results for the V_{upuse} Variable*

	Static Surface Water Storage			Dynamic Surface Water Storage		
V_{upuse}	Mean Simulated Area (m^2)	Normalized Area	SSWS FCI	Days Stage Above Mean Area	Normalized Time	DSWS FCI
1.00	22850	1.00	1.00	1470	1.00	1.00
0.75	23032	1.01	0.98	1500	1.02	0.96
0.50	23686	1.04	0.96	1650	1.12	0.92
0.25	24431	1.07	0.94	1700	1.16	0.88
0.10	23432	1.03	0.92	1580	1.07	0.85
0.00	26162	1.14	0.91	2030	1.38	0.83

* The greyed areas note differences between the FCI score and the simulated score in excess of 10 percent.

CONCLUSIONS: The following conclusions can be drawn from this analysis:

- The coupled hydrologic model is able to simulate the general hydrologic behavior near wetland P1 in the Cottonwood Lake Area as determined by the reasonable agreement between the observed and simulated stages.
- Simulations indicate that surface water flows provide large-magnitude, short-duration fluid fluxes. In general, groundwater discharges provide lower-magnitude, longer-duration fluxes with the inflows typically occurring in the spring, late fall, and early winter months. In the late winter, early spring, and in the summer months, the net groundwater flow is outward to the regional groundwater flow system.
- Scoring algorithms for the maintenance of the static and dynamic surface water storage are correctly accounting for the V_{source} parameter. The normalized simulated FCI was identical to the current definition of the FCI.
- Scoring algorithms for the maintenance of the static and dynamic surface water storage are not correctly accounting for the V_{out} parameter. The current scoring algorithm creates a stronger dependence of the V_{out} variable than was calculated in either simulations of the static and dynamic surface water storage.
- Scoring algorithm for the maintenance of the static surface water storage are correctly accounting for the V_{subout} parameter. The current definition of the dynamic surface water

storage FCI does not include the V_{subout} variable, but the hydrologic simulations indicate a strong dependence.

- The scoring algorithms for the maintenance of the static and dynamic surface water storage are not correctly accounting for the V_{pore} parameter. The current definitions yield a lower static and dynamic FCI with lower V_{pore} values, yet the simulations indicate that lower V_{pore} values yield more ponded water and larger FCIs.
- The scoring algorithms for the maintenance of the static and dynamic surface water storage are not correctly accounting for the V_{upuse} parameter. The current definitions yield a lower static and dynamic FCI with lower V_{upuse} values, yet the simulations indicate that lower V_{upuse} values yield more ponded water and larger FCIs.

Table 6 summarizes the results of the numerical analysis of the HGM approach. Table 6 shows how the current definitions of the static and dynamic surface water storage FCI's compare to the simulated FCI's.

Table 6
Agreement Between the Current and Simulated FCI Definitions

Variable	Static FCI	Dynamic FCI
V_{source}	Good	Good
V_{out}	Poor	Poor
V_{subout}	Good	Poor - Not Included
V_{pore}	Bad	Poor
V_{upuse}	Bad	Poor

RECOMMENDATIONS: Based on the results of this study, it can be seen that there is a need to improve the scoring algorithms for determining HGM indices relative to static and dynamic functioning of the wetlands. The ideal method to improve these scoring algorithms is to employ a physically based model, such as that used in this study. However, requiring the development of models for each wetland site would defeat the purpose of the HGM procedure. An alternative method would be to develop simplistic analytical relationships to describe the HGM indices that act as analogs to the physically based models. This can be accomplished by employing an intelligent model selection and parameterization (IMSP) algorithm. An IMSP algorithm simultaneously selects the analytical functions that best represent a given data set and estimates the parameters that provide the best fit to the data set. The data sets used to develop analytical relationships to describe HGM indices would be developed using the numerical models for reference sites in the prairie pothole region. For each reference site, a numerical model could be constructed. Then an extensive set of wetland variables could be altered, and the corresponding changes in the wetland indices could be tabulated using the results of the numerical models. This would be similar to the procedure presented in this report. These data sets, containing wetland variables as inputs and wetland functioning indices as outputs, could then be used in an IMSP procedure to develop the wetland functioning equations. To accomplish this, several other steps must also be taken, including:

- Developing numerical models for multiple reference sites in the prairie pothole region.
- Including processes in the numerical model to account for the wetland variables V_{wetuse} and V_{sed}.
- Investigations using the numerical models to understand the interactions between the wetland variables.

POINTS OF CONTACT: This technical note was written by Drs. Greg Pohll and John Tracy, Water Resources Center, Desert Research Institute, Reno, NV. For additional information, contact the Program Manager of the Characterization and Restoration of Wetlands Research Program, Dr. Russell Theriot (601-634-2733, *therior@wes.army.mil*). This technical note should be cited as follows:

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