State of Washington Water Research Center

Annual Technical Report

FY 1999

Introduction

The State of Washington Water Research Center is committed to a) engage state university faculty in a meaningful discussion of water-related issues with state and federal agencies and the general public and b) foster relevant university research, education, and outreach activities that provide solutions to these issues. To accomplish these goals, the Center has developed this year a new, more dynamic web page, has begun the preparation of an electronic newsletter, and has intensified its efforts to reach out to agencies, organizations and faculty throughout the state. To promote research and outreach, the Center was organized into five programs (Watershed Management, Water Resources and Biotic Systems, Groundwater Systems, Irrigated Systems, and Outreach and Education). These programs have helped to prepare several multidisciplinary research proposals and provide better links between faculty and the Center. The Center has also been involved in international research and educational activities. It is within this overall context that the USGS-funded project activities reported in this document must be inserted. These projects provide a solid core to the diverse efforts of the Center. Water quality continues to be the major issue of concern in the state, magnified by impacts on the habitat of several endangered species of salmonids. Compliance with the Clean Water Act and the Endangered Species Act is and will be an important driver of the activities of the Center in the future.

Research Program

Basic Project Information

Basic Project Information	
Category	**Data**
Title	Impact of Climatic Variations on Flood Magnitude and Frequency in Three Hydroclimatic Regions of the Western U.S.
Project Number	C-03
Start Date	09/01/1997
End Date	12/31/1999
Research Category	Climate and Hydrologic Processes
Focus Category #1	Floods
Focus Category #2	Climatological Processes
Focus Category #3	Geomorpological and Geochemical Processes

Lead Institution	State of Washington Water Research Center

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
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P Kyle House	Unknown	Nevada Bureau of Mines and Geology	02

Problem and Research Objectives

Hydroclimatic variability over a wide range of spatial and temporal scales is directly linked to attendant variations in the magnitude and frequency of severe regional flooding events in the western U.S. Understanding this linkage is critical for improving flood-frequency forecasting and water resources management in this region. The spatial and temporal distributions of large floods in the western U.S. are largely controlled by persistent, anomalous patterns in hemispheric to global-scale atmospheric and oceanic circulation that directly influence flood-generating storm systems. Variability in flood frequency over short and long time scales thus provides an insight into variability in related larger-scale climatic phenomena over the same time scales. This study employed paleoflood analyses to compare the influence of decadal- to millennial-scale climatic variability on the magnitude and frequency of large floods on rivers in three distinct hydroclimatic regions of the western U.S: the Southwest, Northwest, and western Great Basin. This is the first study to construct regional paleoflood chronologies for rivers in the Northwest and Great Basin, and this aspect of the project alone will greatly increase the accuracy of flood-frequency forecasting in these areas. In addition, our comparison of paleoflood chronologies from three areas of the western U.S. will allow us to go one step further and determine whether there are consistent, predictable, long-term similarities or differences in the occurrence of large floods among these distinct hydroclimatic regions and investigate whether the regional differences in the timing and controls on floods in the short-term records hold true for the response of large floods in the three regions to longer-term climatic variations.

Methodology

The above objectives were accomplished through the following methods: 1) Field and laboratory analyses of paleoflood deposits on multiple rivers in each region, including stratigraphy, sedimentology, and radiocarbon dating; 2) Revised flood-frequency analyses of individual rivers incorporating paleoflood data; 3) Examination of the large-scale climatic factors associated with modern floods as an analog to the paleofloods; 4) Comparison of the long-term variability in paleoflood frequency with regional and global paleoclimatic data covering the last several 100s to 1000s of years to determine the regional effects of climate change on extreme flood events 5) Comparison of the temporal distribution of paleofloods among the three regions to determine whether this pattern is consistent with differences observed at annual time scales in the modern record.

Principal Findings and Significance

PALEOFLOOD RESEARCH The paleoflood analysis of rivers in each of the three hydroclimatic regions extended the records of large floods on these rivers by several thousand years. These data were used in flood frequency estimates and comparisons between the timing of floods and the climatic conditions among the three regions. PALEOFLOOD RESEARCH IN THE WESTERN GREAT BASIN The research on this project in the Great Basin has focused on the Walker, Humboldt, and Truckee Rivers. Research on the Humboldt River has also been supported through the USGS Statemap program. Humboldt River, Nevada The Humboldt River is a large, meandering river with a broad floodplain marked by numerous abandoned meander belts and related relict floodplain surfaces. In the area currently being studied, the Humboldt drains more than 8,800 mi2 of the central Great Basin. Several abandoned meander belts are characterized by geometry that is strikingly different from the present-day configuration of the river. In some cases, meander amplitude and wavelength are nearly an order of magnitude larger in meander belts that have been tentatively dated to between 2000 and 3000 years old. These patterns in fluvial behavior indicate that the river is clearly sensitive to hydrological changes due to climatic variability in the middle and late Holocene. Detailed mapping, and limited planimetric, and stratigraphic analyses were carried out to establish baseline paleohydrological data to help evaluate changes in regional average hydroclimatological conditions and thus an important point of comparison with the regional paleoflood data set which reflects the occurrence of discrete, extreme events. We performed detailed planimetric analysis of the abandoned meander belts to estimate paleodischarges and performed some excavations of the floodplain to characterize the sedimentology of the relict channels and to ensure that were acquiring samples from the appropriate stratigraphic contexts for age-control for the paleochannel systems. The Truckee River The research on the Truckee River focused on evaluating the frequency of large floods on the Truckee in the context of paleoflood information. In particular, we were interested in estimating the exceedence probability of the 1997 flood in the context of a variety of data types. In this analysis we developed a simple hydrological model to remove the influence of flood control reservoirs on peak flood magnitudes on the Truckee. This allows for a more realistic characterization of the natural hydrologic variability in the flood series and a more instructive comparison with paleoflood data. The US Bureau of Reclamation model fldfrq3 is being used for this analysis. This model allows for the incorporation of paleoflood data and related uncertainties into the statistical analysis. West Walker River The Walker River (California and Nevada) experienced extreme flooding in January 1997. A portion of our research project on paleofloods in the Western Great Basin has focused on this river. Our principal goal was to evaluate the paleohydrological context of the 1997 flood and to evaluate different types of geomorphic criteria that are appropriate for evaluating paleoflood magnitude and frequency in this region. On the Walker River, dendrochronological analysis of trees rooted in fluvial deposits and hillslopes that were undercut by the 1997 flood has proven to be a particularly useful technique. Analysis of 42 trees in 6 study reaches suggests that it is likely that the 1997 event may have been the largest, most erosive flood on the Walker River in the last 330 years. We also identified and described localized slackwater flood deposits that support this interpretation. Our recently completed analyses indicate that it is likely that within the last 300-600 years, the largest floods occurred in 1997 and the 1860s. The paleoflood information from the west Walker River was incorporated into a Bayesian flood frequency model to evaluate the general frequency of extreme events on this river as well as to place the 1997 event into its appropriate context. PALEOFLOOD RESEARCH IN THE NORTHWESTERN UNITED STATES Field studies were completed on the Grande Ronde River (Oregon), upper and lower John Day River (Oregon), Deschutes River (Oregon) and the Snake River (Oregon and Idaho). Reconnaissance field work was conducted on the Powder, Burnt and Malheur Rivers of central Oregon, and the final results from these rivers will also be included in the final analysis and publications from this project. John Day River The paleoflood and flood-frequency study of the upper John Day River near Service Creek (Muleshoe site) in central Oregon was completed in Fall, 1998. Results revealed evidence of 23 individual paleofloods which occurred during the past 2000 years. At least 8 of these floods occurred in the last 1630 years and are comparable in size or larger than the largest historic flood in 1964. Discharge estimates associated with individual paleofloods were calculated using the HEC-2 step-backwater method. The minimum discharge calculated for the highest flood deposit at the study site was 1150cms (40600cfs). By comparison, the largest historical flood of record on the John Day River, which is represented by an inset slackwater deposit, occurred in 1965 and had a discharge of 1138cms (40200cfs). Timing of paleofloods was determined from radiocarbon dating of organic material within the deposits. Charcoal from the oldest deposit yielded a radiocarbon age of 1790 +/- 40 B.P., and several of the subsequent floods dated between 1800 and 1600 B.P. This conspicuous clustering of flood events indicates a discharge threshold which was exceeded only by a few extreme floods. The paleoflood data were incorporated into a revised statistical flood-frequency estimate for the John Day River using the U.S. Bureau of Reclamation model fldfrq3. The 100-year flood estimate for this river based solely on the modern gauged data is 1170 cms, and it was lowered substantially to 910 cms when combined with the paleoflood data. Grande Ronde River Three sites of paleoflood deposits were described and dated on the Grande Ronde River in northeastern Oregon. Results indicate a record covering the last 8000 years on this river. Deschutes River Field studies and surveys have been completed at three major sites on the Deschutes River in central Oregon. Eighteen samples were submitted for radiocarbon dates, revealing a flood chronology for this river that extends back at least 4000 years. The magnitude and frequency of floods on this river is of critical interest because of the dam relicensing that is presently underway just upstream of the study reach. Cross sections were surveyed in September, 1999 for use in the HEC-RAS modeling of the paleoflood discharges. This flood of record occurred on this river in 1996, and debris left by this flood provides a good reference stage for the paleofloods and a calibration for the discharge calculations. The majority of the paleofloods preserved in the record on the Deschutes River exceed the 1996 discharge. The timing and discharges of the paleofloods will be incorporated into the U.S. Bureau of Reclamation fldfrq3 model to develop revised flood-frequency estimates for this river. Snake River Field studies were conducted on the Snake River in western Idaho and eastern Oregon. Flood deposits along the Hell's Canyon reach of the Snake River indicate that at least six late-Holocene extreme floods with stages greater than 5m above bankfull stage have occurred on this section of the river in the last 3800 years. Examination of slackwater sands and silts along river banks in bedrock canyons such as Hell's Canyon reveal a river's pre-historic record of extreme floods, and analysis of anomalous meso-and synoptic-scale climate activity has proven a useful tool in determining the meteorological cause of floods along rivers. These two methods of flood variability analysis were combined to infer the causes of floods that occurred over the last few thousand years on the Snake River, using the modern flood-climate relationship as an analogue of the climatic conditions associated with past floods. PALEOFLOOD RESEARCH IN THE SOUTHWESTERN UNITED STATES Much of the paleoflood research for the southwestern United States was already compiled by the authors before the beginning of this project and is being used for comparison with the new data from the other two hydroclimatic regions in the Northwest and Great Basin. We did collect additional data from the Bill Williams River in western Arizona, and the Verde River in central Arizona. Most paleoflood data from the Verde River was compiled in previous investigations and we only collected supplementary data in this project. More extensive work was performed on the Bill Williams River. Collection of stratigraphic and topographic data was completed on the Bill Williams River in a narrow gorge below Alamo Dam. In the study reach we examined a 6.5 meter thick accumulation of flood slackwater deposits immediately upstream from the constriction. Two samples from the base of the section yielded radiocarbon dates calibrating to about 1400-1520 AD. At this site, the upper 3 meters of flood deposits correspond to extremely large floods in the late 1800s and early 1900s. Hydraulic modeling of the study reach indicates that the magnitude of the floods associated with the slackwater deposits range from 45,000 cfs to 144,300 cfs. HYDROCLIMATIC ANALYSIS The flood hydroclimatic analysis of rivers in this study is currently underway. Discharge records have been collected from several rivers throughout the interior northwestern region. An attempt was made to include gauging station records on all rivers on which paleoflood analyses were being conducted, with the addition of other rivers in the region to gain geographically diverse coverage. The dates and magnitudes of floods with discharges greater than the 10-year recurrence interval discharge have been selected from each river for inclusion in the final hydroclimatic analysis. The data were being sorted be region, and the dates of these floods are being combined to create composite anomaly maps of atmospheric pressure and circulation patterns associated with large floods in each sub-region. These maps are begin created using an interactive WEB site run by the National Oceanographic and Atmospheric Administration (NOAA). Given a selection of specific dates, this program calculates the composite departure from mean atmospheric pressure on the combined dates of floods, using a historical data base of daily and monthly mean atmospheric pressure data across a northern-hemisphere grid. If all of the large floods within a region are associated with a similar large-scale atmospheric circulation pattern, then the composite anomaly map of atmospheric pressure for the dates of the floods indicates a single, strong pattern. The Snake River in Hells Canyon Idaho is the first region for which a hydroclimatic analysis of the modern floods has been conducted. The results indicate that a similar large-scale atmospheric circulation anomaly is responsible for the majority of the floods that exceed the 10-year recurrence interval discharge on this river. This pattern consists of an anomalous low-pressure system in the central-eastern Pacific that moves northeastward over the study area, and a high-pressure system that blocks the system from moving over the hydroclimatic region in the Southwestern U.S. This pattern is in sharp contrast to composite anomaly patterns for floods in the Southwestern U.S., in which the low-pressure system is much farther south along the coast of western California. Detailed examination and characterization of the differences in these circulation patterns is still underway. The results will be used to document the types of climatic conditions conducive to flooding in the different hydroclimatic regions, and will also be compared with the paleoclimatic conditions at the times of past floods in the different regions. For additional information on this project, visit the State of Washington Water Research Center website at http://www.wsu.edu.swwrc/ under the heading Research Projects.

Descriptors

Flood Frequency, Paleofloods, Climate, Geomorphology

Articles in Refereed Scientific Journals

Book Chapters

Hirschboeck, K.K., Ely, L.L., and Maddox, R., (in press), Hydroclimatology of meteorologic floods, in Wohl, E.E. (ed.), Inland Flood Hazards: Human, Riparian and Aquatic Communities: Cambridge University Press.

Dissertations

Hosman, K. (in press), Paleofloods and flood frequency on the Deschutes River, central Oregon: M.S. Thesis, Dept. of Geological Sciences, Central Washington University, Ellensburg, WA. Kellogg, Mike, in prep., Paleoflood Hydrology of the Carson river, Nevada and California, M.S. Thesis, Graduate Program of Hydrological Sciences, University of Nevada, Reno. Mann, M., in prep. Using geomorphic information in extending the flood record of the West Walker River, California, MS Thesis, Graduate Program in Hydrologic Sciences, University of Nevada, Reno, 192 pp. Musler, H. M., 1999, Evaluating flood frequency on the Truckee River, Nevada using systematic, historical, and paleoflood information, MS Professional Paper, Graduate Program in Hydrologic Sciences, University of Nevada, Reno, 58 pp.. Orth, S. A., 1998, Refining flood-frequency estimates with paleoflood deposits: John Day River, north-central Oregon: M.S. Thesis, Dept. of Geological Sciences, Central Washington University, Ellensburg, Washington, 146 p Rhodes, G.B., in press, Paleofloods on the Snake River, Idaho, as indicators of Holocene climate in the northwestern U.S.: M.S. Thesis, Department of Geological Sciences, Central

Washington University, Ellensburg, WA.

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Ely, Lisa L. and P. K. House, 2000, Impact of Climatic Variations on Flood Magnitude and Frequency in Three Hydroclimatic Regions of the Western United States. State of Washington Water Research Center Report SWWRC-C-03. Pullman, Washington. 10 pp.

Conference Proceedings

House, P. Kyle, in press. Proceedings, Second International Paleoflood Conference and Field Trip, Prescott, Arizona. Sept. 27-Oct. 1, 1999. Monograph, American Geophysical Union. Rhodes, G. and Ely, L.L., in press, A small look at the big picture: Paleofloods on the Snake River as indicators of Holocene climate in the northwestern U.S.: Proceedings of the Second International Paleoflood Conference, Prescott, Arizona, Sept. 27-Oct. 1, 1999. House, P.K., in press, Complexities of paleoflood stratigraphy on the Verde River, Arizona and the value of comprehensive paleoflood hydrology: Proceedings of the Second International Paleoflood Conference, Prescott, Arizona, Sept. 27-Oct. 1. Orth, S.A. and Ely, L.L., 1998, Reconstructing paleoflood history with slackwater deposits: John Day River, north-central Oregon: GSA Abstracts with Programs, v. 30, No. 7

Other Publications

House, P.K., 1999, Lessons learned from paleoflood stratigraphy in the Verde River Basin, Arizona, Invited Paper Presented at the First International Conference on Drainage Basin Dynamics and Morphology, Jerusalem, Israel, May 22-29, 1999. House, P.K., Pearthree, P.A., Klawon, J.E., McDonald, E.V., and Levish, D.R., 1999, Holocene flood history of the lower Verde River, Arizona, Paper presented at the Annual Meeting of the Arizona-Nevada Academy of Science, Flagstaff, AZ, April 17. House, P.K., Klawon, J.E., and Pearthree, P.A., 1999, Field Trip Guide for the Second International Paleoflood Conference-Reports on Paleoflood Studies on Large Rivers and Alluvial Fans in Central and Western Arizona, unpublished. House, P.K., Ramelli, A.R., and Wrucke, C.T., 1998, Geologic Map of the Battle Mountain Quadrangle, Nevada, Nevada Bureau of Mines and Geology Open-file Map 98-EE. Ramelli, A.R., House, P.K., Wrucke, C.T., and John, D.A., 1999, Geologic Map of the Stony Point Quadrangle, Nevada, Nevada Bureau of Mines and Geology Open-file Map 99-AA. Rhodes, G. and Ely, L.L., 2000, A small look at the big picture: Paleofloods on the Snake River as indicators of Holocene climate in the northwestern U.S.: Geological Society of America Abstracts with Programs, GSA Cordilleran Section Meeting, Vancouver, British Columbia, April, 2000.

Basic Project Information

Basic Project Information	
Category	**Data**
Title	A Problem-Solving Tool for Mitigating the Impact on Water Quality of Management Practices in Small Rural Watersheds
Project Number	C-02
Start Date	09/01/1997
End Date	08/31/2000
Research Category	Water Quality

Focus Category #1	Hydrology
Focus Category #2	Management and Planning
Focus Category #3	Non Point Pollution
Lead Institution	State of Washington Water Research Center

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
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Shulin Chen	Associate Professor	Washington State University	02
Jan Boll	Assistant Professor	University of Idaho	03
Keith Saxton	Unknown	US Department of Agriculture	04
Donald McCool	Unknown	Washington State University	05
Larry King	Professor	Washington State University	06
Thomas Hess	Associate Professor	University of Idaho	07
Myron Molnau	Unknown	University of Idaho	08

Problem and Research Objectives

A productive approach for watershed water quality improvement is to act at relatively low levels of integration (i. e., small watersheds). At this scale, the number of landowners and water quality issues involved is limited. Analysis and implementation of corrective solutions are more manageable than when evaluating large basins as a whole. Evaluating water quality changes in smaller watersheds also means that changes in watersheds within a larger basin can be compared and analyzed. The objective of this project is to develop a computer-based tool for small watershed analyses applicable to the Pacific Northwest (PNW) where rain and snowmelt, often on frozen soil, dominate runoff and sediment production. However, the framework must be generic enough for applications elsewhere.

Methodology

The following tasks will be accomplished to address the objective of this study: 1. Develop a geographic information system for data management and display. 2. Finalize and test a weather generator to produce long-term series of daily weather data. 3. Develop a hydrologic model that includes the effects of snow accumulation/melting and frozen soil conditions as they occur in the Pacific Northwest. 4. Develop a cell-based surface and subsurface-hydrology simulator, including overland water and contaminant flow, and groundwater loading estimates. 5. Improve and test a simulator of productivity and water and nutrient balances for crop, range, and forestlands to be applied in each cell. 6. Develop a state-of-the-art user interface to handle the GIS-based watershed database and weather records, parameterize the simulators, specify changes in management practices over crop, range, or forested lands, and provide utilities for output customization, risk, and frequency analyses. 7. Apply the tool to a real watershed as a case study.

Principal Findings and Significance

The development of a protocol for interfacing simulation models with ARC/INFO GIS software was completed. The Spatial Analyst for ARCView, a commercially available and widely used software package was customized for geographical/spatial hydrologic analyses that are relevant to this project. Integration of ArcView and the GIS functions required by the watershed analysis tool was also completed. The technical development, testing, and the development of a user-friendly software package for ClimGen (weather generator) was finalized, including additional features to improve temperature generation and to estimate solar radiation and vapor pressure deficit from temperature data, the latter allowing the application of the watershed model to areas with limited availability of weather records. The Hydrology Component In the Pacific Northwest (PNW), the risk of large runoff and erosion events is often complicated by the occurrence of three or four cycles of freezing and thawing during the winter. High runoff events are usually associated with fast thaw of the soil due to rising temperatures or warm precipitation over the watershed. In addition, due to migration of water to the frozen layers, when the soil thaws, it becomes saturated and very susceptible to erosion. As soil freezes, the infiltration is reduced, the stability of the aggregate is decreased, and consequently, runoff, erosion, and non-point pollution are expected to increase. To incorporate these effects in the watershed model, a soil freezing/thawing submodel based on the Stefan solution with heat storage was developed. This submodel was tested against field data and the SHAW model (a detailed energy balance-based, short time step model) outputs for the same set of conditions. Simulated values of duration of the freezing periods, number of freezing cycles per season, and frost depth were compared with measurements. Snow and soil frost data were measured at the Palouse Conservation Field Station (PCFS) near Pullman, WA from 1983 to 1991. Climatic data, including daily air temperature, precipitation, radiation, and other variables were also available. The submodel performed well in predicting soil freezing under the conditions of the PNW. The number of soil frost cycles was simulated well while the average length of the cycles was somewhat overestimated. The SHAW model further overestimated the average length of the frost cycles compared with our submodel. The high variation in the length of the cycles was well simulated by both models. Similarly, the timing of the date where freezing starts was also satisfactorily simulated. A lag of around 5 and 3 days, for the SHAW and our submodel, respectively, was obtained. The frost depth was overestimated, on the average, by 1.2 cm, with a range from 12.2 cm underestimation to 8.9 cm overestimation. The SHAW model underestimated frost depth by 6.0 cm on the average, with a range from 19.0-cm underestimation to 6.1-cm overestimation. Adequate prediction of snow depth appeared critical in the simulation of frost depth. Also in terms of hydrologic modeling, a one-dimensional finite difference numerical solution for water flow in the vadose zone was completed, including greater flexibility in boundary conditions, time step, and soil layering with the purpose of increasing the robustness of the numerical solution and/or computational speed. A sub-model to disaggregate daily rainfall into 30-minute intervals was finished. A numerical model (NM) for runoff calculations was implemented and compared with the traditional curve number approach (CN). Both methods were tested using 13 years of field data that included several soil surface conditions. The NM model showed the best agreement with the observed data, although some overestimation of the runoff for conditions that include residue and grass was found during the winter and, more markedly, in spring. Underestimation was found under bare soil conditions, which was attributed to soil surface sealing. The performance of the model improved when the hydraulic conductivity of the top layer was reduced by a 10-fold to indicate degradation of surface structural conditions. The model seems sensitive to this parameter, which may show significant spatial and temporal variation. Temporal variations can be attributed to soil structure deterioration after winter runoff, producing crusting and soil sealing that leads to less infiltration capacity. The CN model performed adequately for bare soil, but it overestimated runoff for the rest of land uses. This model could be an alternative if the numerical solution is not available, provided that calibration of the curve number could be performed to better represent residue and grass cover conditions. The original CN model did not simulate adequately runoff and clearly underestimated for all land uses but grass. Other activities for this year included the continuation of testing and validation of a sub-surface hydrology component for the model. As described in the last progress report, the lateral hydraulic conductivity is a sensitive parameter in the model. To further understand the magnitude of lateral saturated hydraulic conductivity in the Palouse region, a 18 m x 30 m isolated hillslope plot was installed at the Troy catchment. Upslope lateral flow was diverted using a tile line installed on the hydraulically restrictive fragi-pan located approximately 0.75 m below the soil surface. The downslope lateral flow was collected in a tile line and measured using an automated tipping bucket installed in an insulated winter shelter. A surface runoff trough was installed and plumbed to a tipping bucket to quantify the magnitude and timing of surface runoff. The plot boundary was isolated using sheet metal plot borders. To ensure subsurface water did not bypass the tile lines, plastic sheeting was installed along the borders from the fragi-pan to the soil surface. Three automated piezometers measured perched water table fluctuations twice a day while five piezometers were measured during each site visit to identify the drawn down curve of the water table to the downslope tile line. The data collected from the plot will be used for several purposes. First, a mass balance of the water in the plot will give an estimate of the amount of water that vertically percolates through the fragi-pan layer. Secondly, the rate at which the plot drains during the spring melt will be used to calculate the effective lateral hydraulic conductivity of a 18 x 30 m block of soil in a landscape. The calculated lateral hydraulic conductivity will be compared to watershed scale estimates using drought flow analysis and soil core scale (< 10 cm) hydraulic conductivity. These results can also be used to assess the sensitivity of the model to scale. This work is currently being completed. A bromide tracer study was conducted within the hillslope plot during melt conditions. Bromide was placed 7 m upslope of the tile line. The first bromide was detected at the tipping bucket after 9 hours, indicating a travel time of approximately 19 m/day. The peak bromide concentration occurred after 60 hrs. Both these findings confirm the large influence of subsurface lateral flow on the hydrology of the catchment. This experiment will be further analyzed to calculate lateral hydraulic conductivity for the site. In addition to the hillslope plot, monitoring continued at the Troy, Idaho, catchment including automated perched water table measurements throughout the 2 ha catchment, surface runoff measurements at the outlet, and a complete set of meteorological parameters. In order to test and validate the snow melting algorithm in the model snow water equivalent depth was measured at three locations representing different solar incident angles and snow drift patterns. Measurements were made weekly during snow accumulation and more intensively during melting conditions. Snow depth measurements were also made at each piezometer location (140 total) on two different days during snow melting conditions to validate how well the model can represent the spatial distribution of snow melting. As discussed above, in the Palouse region the runoff and erosion is highly accelerated by a shallow frozen soil layer. When a soil freezes the soil pores fill with ice which significantly reduces infiltration and increases runoff. In order to quantify the reduction in infiltration due to a frozen soil layer infiltration experiments were conducted using a rainfall simulator. Runoff was measured from 1 m2 plots installed before the soil froze in bare and tilled soil. Winter experiments could only be conducted on soil with a relatively thin (<10 cm) frozen soil layer due to the warm winter. The experiments showed that the infiltration on average was limited for a short period of time (~10 minutes) before macro-pores thawed and conducted the water through the frozen soil layer. An analytical solution was developed for overland flow over a hillslope based on the Saint-Venants equations. This solution was designed specifically for the application in a GIS cell-based model. The analytical solution was first tested using published data using a hillslope elsewhere. In the final phase of the project, we will include this solution in our cell-based model to provide flow depth and velocity on an event-basis. The Erosion Component As described in the last progress report sediment detachment, transport, and deposition is based on the stream power approach.). In order to apply and test the erosion component it was necessary to conduct field experiments under typical thawing conditions of the Palouse region. Rill erosion experiments similar to the WEPP cropland soil field erodibility experiments were conducted in the summer on unfrozen tilled soil, in the winter of partially frozen soil, and in the spring on near saturated soil which had settled over the winter due to freeze/thaw cycles. The sediment samples from these experiments are currently being analyzed. These experiments will be used to determine the change in the erodibility of a Palouse soil during distinct seasons of the year. A simple theoretical algorithm based on the work by Hairsine and Rose was developed and can be included in the model as soon as flow depth and flow velocity are determined by the surface runoff module. Inclusion in the model is expected in the final phase of the project. CROPSYST Watershed Model validation The watershed model is currently operational. A first complete version of the user interface, data handling, simulation control, and output handling is available. Current work is focusing on improving the program as the model is tested. Data from the Troy, Idaho, site are being used to validate the current version of the watershed model. Main concern continues to be computational speed and efficiency to increase the relative size of watersheds to be simulated. Additional testing will be performed before the end of the project. For additional information on this project, visit the State of Washington Water Research Center website at http://www.wsu.edu.swwrc/ under the heading Research Projects.

Descriptors

Water Quality, Winter Hydrology, Decision Models, Watershed Management

Articles in Refereed Scientific Journals

Wang, G., S. Chen, J. Boll, C.O. Stöckle and D.K. McCool. (in review) Modeling overland flow based on Saint-Venant equations using a discretized hillslope approach. Submitted to Water Resources Research.

Book Chapters

Dissertations

Peralta, J.M. 1999. Modeling the hydrology of a small agricultural watershed in the Pacific Northwest. PhD Dissertation, Washington State University, Pullman, Washington.

Water Resources Research Institute Reports

Conference Proceedings

Other Publications

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Basic Project Information

Basic Project Information	
Category	**Data**
Title	Evaluating Water Policy Affecting Fish Habitat, Hydrology and Irrigated Agriculture in the Snake River Basin
Project Number	C-04
Start Date	09/01/1998
End Date	02/28/2001
Research Category	Social Sciences
Focus Category #1	Hydrology
Focus Category #2	Irrigation
Focus Category #3	Economics
Lead Institution	State of Washington Water Research Center

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
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Claudio Stockle	Professor	State of Washington Water Research Center	02
Joel Hamilton	Professor	University of Idaho	03
Gary Johnson	Assistant Professor	University of Idaho	04
Marshall English	Professor	Oregon State University	05

Problem and Research Objectives

Changes in water management policies for the Snake River are required as a consequence of the Salmon River Sockeye and the Spring and Summer Chinook Salmon stocks being listed as endangered. The Snake River is heavily appropriated for irrigation and hydroelectric power production, resulting in problems relating to water quantity and quality in Idaho, Oregon and Washington. Further, surface water and groundwater are highly interdependent in the region. Consequently, changes in water policy to assist salmon recovery may dramatically affect the hydrology and the agricultural economy of the region. The overall objective of this research is to evaluate alternative water policy choices for salmon recovery in the Snake River basin for effects on quantity and quality of stream flow, groundwater recharge and discharge, irrigated agricultural production, hydroelectric production, and the region's economy.

Methodology

Research objectives will be accomplished by integrating models of individual and regional crop production, irrigation uniformity, ground and surface water hydrology, and regional economic impacts. The research goal for the second year of this research was to finish development and calibration each of the individual models, to run some water policy scenarios, and to assess the economic impacts of alternative policies. Attention was given to the need for the models to be consistent for the ease of integration.

Principal Findings and Significance

Progress to date consists primarily of data gathering, individual model development, model calibration, and preliminary efforts of model integration. There are six individual models to be integrated: SPRINKS, a model of irrigation efficiency and uniformity; CropSyst, a crop production model; SRAM, a regional agricultural production model; a groundwater hydrology model; MODSIM, a surface water allocation model; and IMPLAN, a regional economic impact model. Crop/water production functions are being developed by integrating SPRINKS and CropSyst. The groundwater hydrology model is being used to develop response functions to incorporate groundwater interactions into MODISM, which models surface water storage and allocation. SRAM and MODSIM will be iterated for each policy alternative. Results from SRAM will input to IMPLAN to estimate the regional economic impact of the alternatives. Crop production functions were developed for zones in the upper Snake River basin represented by climatic conditions at Fort Hall and Twin Fall, Idaho. For surrounding areas, county level yields were obtained, which were used as references to adjust some of the crop parameters in CropSyst so as to improve yield simulation of the different crops involved. Complete weather records were obtained and modified for in CropSyst. In addition, soil data for each area was identified and input files were prepared. Model calibration for alfalfa, corn, spring wheat, sugar beets, dry beans and potatoes under full irrigation were prepared. A reasonable agreement with observed yields was obtained. Simulations for 0 to 100 percent irrigation in increments of 10 percent were prepared. These yields can be used to accommodate any depth of field water application as predicted by SPRINKS for different irrigation uniformity and efficiency scenarios. Additional data analysis will determine patterns of relative yield with respect to relative water supply. Results from these runs will be used to estimate crop production functions for use in SRAM. SRAM has been developed to estimate the change in crop production at the regional level due to changes in water allocation. Data on water deliveries, crop acreage, irrigation efficiencies, crop water use and crop input and output prices were gathered for model development. SRAM was calibrated and tested using the policy scenario of government purchases of one million acre-feet of water to augment in-stream flow. Results from the SRAM model have been compared to the results obtained in the Million Acre Feet study that was separately conducted by the Bureau of Reclamation. In general the SRAM results were relatively consistent with results from the Million Acre Feet study lending some credibility to the SRAM exercise. The SRAM model has been used to examine two alternative million acre-feet scenarios. In alternative one the impact on recreation was minimized at the expense of irrigated agriculture. In alternative two the impact on irrigated agriculture was minimized at the expense of recreation. In each scenario, the water transfer from each region was determined by using MODSIM and those transfers were fed into the SRAM model. The advantage of this approach is that MODSIM does take account of water rights and the hydrology of return flows. The disadvantage of the approach is that MODSIM is unable to account for the relative value of the water in each of the regions along the Snake River. So water is being taken out some regions were it is relatively valuable when other regions where water is less valuable are not transferring as much water. Work is currently underway to use the SRAM model to determine the region from which the water will be transferred from agriculture. Here the water transfer will be determined so that the shadow price of water in the SRAM models is equal across all regions. In this way the economic impact across the entire region can be minimized. The water transfers from the SRAM model will then be fed into MODSIM to determine how the hydrology of return flows modifies the results obtained from SRAM. Work is also underway using SRAM to vary the level of assumed water purchases from the Bureau of Reclamation's one million acre-feet scenario and examine the predicted impact on regional crop production and regional economic impact. In addition, the consequence of dry year versus average year scenarios is also being investigated. Work on MODSIM has focused on two goals. First, enhance our ability of manipulating and interfacing with the MODSIM computer program. Second, develop an understanding of MODSIM as developed by the Bureau of Reclamation model of the upper Snake River basin, from Wyoming to Brownlee Dam on the Idaho-Oregon border. The model is being enhanced to better incorporate ground water interactions, thus being more capable of evaluating effects of land use changes on river flow. The most significant groundwater contributions to the river are in the eastern Snake River Plain, above King Hill. The changes to incorporate groundwater hydrology take the form of new attributes in the model, as opposed to changes in model code. Preliminary groundwater response functions have been used in the Snake River program of MODSIM with good success. Refining these functions will continue throughout the project. So far all of the economic impact analysis using SRAM has been built on output coming from MODSIM. Work is now being conducted where the Regional input-output models were constructed to cover the economy of southern Idaho. Three separate models were constructed representing the eastern region (Idaho Falls), the central region (Twin Falls) and the southwestern region (Boise). Idaho Falls, Twin Falls and Boise make up the three functional economic regions in southern Idaho and represent appropriate regional units on which to conduct economic impact analysis of the kind required by this project. The input-output models have been standardized in terms of reporting format to facilitate translation of model results to spreadsheet and word processor formats. Estimates of regional agricultural impact from SRAM are being fed into the input-output models to estimate the likely regional economic impact of leasing different amounts of water from agriculture for salmon recovery. For additional information on this project, visit the State of Washington Water Research Center website at http://www.wsu.edu.swwrc/ under the heading Research Projects.

Descriptors

Ground and Surface Water Hydrology, Irrigation, Economics, Fish Habitat

Articles in Refereed Scientific Journals

Hamilton, J.R. G. Green and D. Holland "Modeling the Reallocation of Snake River Water for Endangered Salmon." Amer. J. Agr. Econ. 81 (5):1253-1256. 1999.

Book Chapters

Dissertations

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Conference Proceedings

Other Publications

Engle, Paula, and David Holland. "Water Leasing For River Flow Augmentation and Uncompensated Job Loss: A Case Study of South Central Idaho." A.E 99-3., Dept. Ag. Econ., Wash. St. U., Pullman.

1999.

Basic Project Information

Basic Project Information	
Category	**Data**
Title	Remediation of Uranium Contaminated Mine Waste
Project Number	B-03
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Water Quality
Focus Category #1	Solute Transport
Focus Category #2	Hydrology
Focus Category #3	Non Point Pollution
Lead Institution	State of Washington Water Research Center

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Markus Flury	Assistant Professor	Washington State University	01
James Harsh	Associate Professor	Washington State University	02

Problem and Research Objectives

The Pacific Northwest, and particularly the states of Washington and Idaho, contain many mining facilities. Uranium is often a waste product of such mining operations. Leaching of uranium from mining waste poses a threat to the state's ground and surface water resources. Unlike many contaminant metals, uranium is not easily immobilized by neutralizing the acidic waste at the site. Although uranium forms insoluble solids or adsorbs to mineral surfaces at alkaline pH, it also forms soluble carbonate complexes that increase its solubility, availability, and mobility. As a result, reactive materials with the potential to immobilize uranium in the presence of soluble carbonate may be necessary for long-term stabilization of this contaminant. There are two particularly attractive means to immobilize uranium using inexpensive reactive materials. The first is to reduce U(VI), which is the stable form of uranium in an aerobic environment, to U(IV). The reduced uranium forms highly insoluble oxides and hydroxides. In order to release uranium from these solid phases, the uranium must be reoxidized and dissolved from the solid; consequently transport of uranium through the vadose zone and through aquifers is prevented or at least considerably retarded. Zero-valent iron (Fe(0)) can be used to reduce U(VI) to U(IV) and attenuate its release to the environment. Although it has been shown that Fe(0) can decrease uranium solubility and availability to plants, little is known about the rate or extent of the reaction or of its potential for long-term immobilization. The second means for immobilization is the formation of insoluble U(VI)-phosphates. Oxidized U(VI) does not form insoluble oxides or hydroxides as does U(IV), but it will form insoluble phosphate solids such as autunite under favorable conditions. When U(VI) is reacted with apatite, a series of increasing insoluble phosphates are formed, including metaautinite, which is a highly insoluble uranium phosphate. Uranium Geochemistry and Fate in the Environment Almost all on-going and past mining and milling activities release uranium into the geosphere. Knowledge about fate of this uranium in the environment, particularly in the subsurface, is of utmost interest to protect subsurface waters. Since federal law required the U.S. Department of Energy to clean-up many of these sites, research has focussed on studying inventories and remediation strategies for uranium in soil, rocks, and subsurface waters. Remediation strategies encompass either ex-situ (e.g., pump-and-treat) or in situ (e.g., bioremediation or flow barriers) methods. Successful implementation of such strategies requires detailed knowledge of uranium behavior during proposed remediation procedures. Uranium in solution forms many aqueous species as a result of hydrolysis and complexation reactions. These reactions are highly dependent on chemical conditions, particularly pH and concentrations of the complexing ligands. Different uranium species have different affinity for sorption to soil and aquifer materials, mainly because of different charges of the various species. Generally, uranium sorption and precipitation are strongly affected by composition, pH, and temperature of the aqueous phase. Uranium sorption to soil and aquifer materials usually decreases with increasing concentration of carbonates in solution, because of the formation of negatively charged uranium-carbonate complexes. When mine wastes containing uranium are exposed to water and oxygen, uranium is released by a combination of oxidation and dissolution reactions. Uranium deposits generally contain uranium in its reduced form (U (IV)) as the insoluble mineral uraninite. As the deposit is exposed to water and oxygen from mining activities, the redox potential favors the oxidation reaction: The chemical fate of uranium released from uraninite in a natural system is governed by precipitation, adsorption, and formation of solution complexes. Langmuir has reviewed uranium chemistry in ore deposits at low temperature and concluded that sorption to mineral constituents, particularly iron oxides, can govern soluble levels of U(VI) between pH 5 and 8.5, where optimum sorption to oxides occurs. Subsequent laboratory and field studies of sorption on hematite, goethite, and less crystalline ferric oxyhydroxides (e.g. ferrihydrite) have confirmed the strong sorption of U(VI) on these materials. If the Eh of the system drops below about 100 mV, precipitation of highly insoluble U(IV) minerals is possible. Uranyl solids containing silica (coffinite), phosphate (autunite), or vanadate (tyuyamunite) may form if soluble activities of the ligands and uncomplexed uranyl exceed the relevant solubility products. This is unlikely in the region surrounding the Midnite Mine due to low levels of these ligands in the ground and surface waters. In addition to the precipitation and sorption reactions governing UO2+2, if the U(VI) can be reduced again to U(IV), the solubility of uranium will be significantly reduced and its release to the en-vironment slowed, even in the presence of oxygen. Recent work has shown that uranium can be reduced in the presence of Fe(0), resulting in the reprecipitation of insoluble U(IV) minerals. Zero-valent iron has already been used in field-scale pilot projects to reduce Cr(VI) to Cr(III) and the latter precipitates as insoluble chromium oxyhydro-xides, analogous to the uranium reaction. Also analogous in these reactions is the tendency for uranium and chromium to form coprecipitates with iron oxides to further reduce their mobility. In the case of uranium, this will occur even if uranium is reoxidized to the uranyl species which can adsorb or coprecipitate with the iron oxides described in the above paragraphs. Immobilization of uranium under conditions expected in near surface environment may also take place via precipitation as uranyl (UO2+2) minerals, including schoepite (UO3·x(H20)), rutherfordine (UO2CO3), and autunite (Ca(UO2)2(PO4)2), and reduction and precipitation as U(IV) minerals like uraninite (UO2(c)). In this project we focus on the precipitation of uranium phosphates because previous work has shown that these minerals form rapidly in the presence of soluble phosphate or apatite. Apatite has already been shown to successfully sequester other metals including Pb, Cd and Zn. Uranium migration through soil and aquifer material has been reported in several studies. In all of the studies mentioned, uranium transport has been investigated in laboratory columns under carefully controlled pH and ionic strength conditions. Rate of sorption processes have been investigated by Gabriel and others, who found that uranium (VI) sorption to goethite was an equilibrium reaction at pore water velocities of 3.4 x 10-4 cm s-1, but an non-equilibrium reaction at pore water velocities of 3.4 x 10-3 cm s-1. Adsorption of uranium to goethite was found to be reversible with a non-linear (convex) adsorption isotherm. Overall retardation of uranium in the goethite columns was between R = 20 to 30. The observed Langmuir-type sorption led to an accelerated breakthrough of uranium with increasing solution concentration. Increased leaching due to sorption non-linearity has also been observed in quartz columns. There is indication that geological materials have a finite capacity for uranium retention, and that this capacity can be exhausted within a relatively short time period. This finite sorption capacity of geologic material together with the non-linearity of the sorption process may ultimately lead to increased migration of uranium in soils and aquifers. Such behavior is of utmost concern for remediation strategies where uranium is supposed to be adsorbed by artificially introduced materials. Analysis of uranium transport in columns has to consider the major chemical reactions that take place. Due to the multitude of speciation reactions, modeling approaches of uranium transport are confronted with major difficulties to accurately represent the different chemical reactions. Gariel and others used the advection-dispersion equation together with first-order kinetics or equilibrium Langmuir-type sorption to analyze uranium transport through a goethite column. Using a sophisticated approach that coupled physical transport equations with chemical sorption and surface complexation models, Kohler and others could predict uranium retardation in silica columns with an accuracy of 30%. These authors used a simple system with well-controlled pH, ionic strength, and ionic composition of the leaching solution. Considering the difficulties encountered in predicting uranium transport in well-controlled laboratory systems, predictions of uranium transport in heterogeneous field situations appear to be rather uncertain. Further experimental evidence of uranium transport in porous media is therefore necessary to improve our understanding of uranium fate in the environment and to enhance our ability to predict uranium transport in porous media. Objectives The objective of this study is to test the efficacy of apatite to extract uranium from ground water contaminated from mining operations. Specific objectives are to: 1. Conduct transport experiments of uranium through columns containing apatite. 2. Evaluate efficacy of uranium extraction by apatite as a function of ground water flow velocity, pH of ground water, and carbonate content of ground water. 3. Determine reaction rate coefficients for the uranium reactions with apatite.

Methodology

Mine Location The research conducted is concerned with geochemical and hydrogeological conditions at the Midnite Mine in Eastern Washington. The Midnite Mine is located on the Spokane Indian Reservation. The Spokane Tribe has been working for several years with the former Bureau of Mines, Bureau of Land Management, Bureau of Indian Affairs, and the Department of Public Health of the State of Washington. Much of the effort to date has focussed on characterization of contaminant reactivity, location, and extent, aquifer description, and water treatment of acidic waters loaded with uranium and other metals. Uranium concentrations in groundwater at the Midnite Mine were determined to be in the range of 10 and 100 mg L-1 (wells 3M and 4S). Uranium Uranium solutions have been prepared from UO2(NO3)2·6H20 in standard solution of 1000+5 mg L-1 obtained from Ricca Chemical Company (Arlington, TX 76012). The uranium isotope is U238 and the oxidation state in the uranyl ion UO2+2 is U(VI). Porous Material The porous materials used for the column was North Carolina Apatite. North Carolina Apatite has been proposed a cost-effective material for heavy metal adsorption. Batch Studies In a batch study, we investigated the reaction of uranium(VI) nitrate with North Carolina Apatite at several pH values ranging from 2 to 8 at an uranium concentration of 25 mg L-1. Subsamples of solids and solutions were removed successively at increasing time intervals to determine the change in solution concentration with time. We examined the solid phases with both x-ray diffraction and electron optical techniques. Column Transport Experiments Glass columns were packed with North Carolina Apatite under saturated conditions. The end plates of the columns consist of porous polypropylene disks to assure uniform flow within the column. Tygon tubing and a silicon 3-way valve were used to connect the columns to the solution reservoirs and the sample collectors. Sorption tests have shown negligible sorption of uranium to these column materials. Column outflow is collected in approximately 5 mL increments with a fraction collector. This outflow volume guaranteed sufficient amount of solution for chemical analysis, and has been shown to be adequate to characterize the hydrodynamic properties of the column. The experiments were conducted as follows: 1. After packing, the columns were leached with a buffer solution of 0.01M Ca(NO3)2 and pH-adjusted to pH 5.5 with Ca(OH)2. This procedure pre-conditioned the column with a specific ionic strength and pH. Columns were be packed and operated under saturated conditions. 2. A conservative tracer (CaBr2) was introduced as a step input. Samples were collected and bromide concentrations analyzed. The bromide breakthrough were allow us to determine the hydrodynamic properties of the columns. 3. After the bromide test, the columns were again leached with several pore volumes of the Ca(NO3)2-buffer solution to prepare the column for the uranium test. 4. Uranium solutions were then introduced as a continuous step input. Samples were collected at the outflow with the fraction collector and analyzed for uranium. The chemical analysis were conducted concurrent with the column experiment to assure that breakthrough of uranium is observed. 5. All outflow samples were collected in plastic sampling tubes. 6. At the end of the column experiments the columns were dissected in several depth increments and apatite samples were analyzed with SEM and EDXS as described below. Chemical Analysis of Column Outflow Bromide in the column outflow from the hydrodynamic test has been analyzed with a bromide electrode. A six point calibration was performed. Quality control (QC) was assured by using separate QC standard samples every tenth sample. Uranium concentrations in the column outflow samples were analyzed by atomic emission spectrometry with inductively coupled plasma (ICP-AES, Jobin-Yvon JY 24). A five point calibration was used. Standards were prepared from a 10 mg/L uranium standard solution. Quality control (QC) was assured by using separate QC standard samples every tenth sample. Aqueous outflow samples from the apatite columns were directly used without pretreatment and injected in the ICP-AES. SEM and EDXS X-ray microanalysis in combination with scanning electron microscopy has been used to qualitatively assess uranium contents at apatite samples taken from the soil columns. Columns were divided into increments of 0.5 and 1 cm. Apatite was dried at 60°C for 18 hours, fixed onto stainless steel disks, and coated with a thin film of carbon. SEM images were recorded with a Hitachi S-170 SEM. Several X-ray energy spectra of the apatite grains were recorded per sample to obtain a representative spectrum of each depth increment. Non-treated samples were used as a blank to obtain the background uranium content of the apatite. The X-ray microanalysis has been done with an energy dispersive spectrometer. Uranium counts (at 3160 eV) were related to Ca counts (at 3678 eV), and the U/Ca ratio was used as a relative concentration measure for uranium in the sample. We assume in this procedure that the Ca contents of the samples (Ca counts) are constant and do not change with depth in the columns. SEM images were inspected optically for changes in surface morphology of apatite grains. Uranium Extraction and Chemical Analysis Apatite material taken from the columns was washed with an aqua regia solution (mixture of hydrochloric acid and nitric acid at a 3:1 ratio) to extract uranium. The procedure is described in the following. 1. Mix 750 mL of concentrated hydrochloric acid (HCl) with 250 mL of concentrated nitric acid (HNO3) in a large pyrex beaker. Pour the HNO3 slowly into the beaker containing the HCl. 2. Allow the aqua regia mixture to cool before using. 3. Weigh quantitatively one gram of the soil sample and place into a Teflon beaker. 4. Add 50 mL of aqua regia to the Teflon beaker. 5. Turn on the hot plate and place the beaker onto the hot plate. 6. Do not allow the acid to boil and spatter. Apply heat gradually and check the solution to ensure it does not spatter. 7. Leave beaker on the hot plate for two hours. Continually check the solution to ensure it does not go dry. 8. Add aqua regia in 10 mL increments if solution is approaching dryness. 9. After two hours, turn off the hot plate and allow the sample to cool. 10. Transfer the entire sample into a centrifuge tube using 5 mL deionized water. 11. Place the tube in a centrifuge and spin down at 3000 rpm for 10 minutes. 12. Pour and collect the supernatent into a separate container. 13. It is very important to measure the final volume of solution. Bring the supernatent up to 40 mL with deionized water. 14. Samples are now ready for analysis.

Principal Findings and Significance

Batch Studies The x-ray diffraction patterns showed that rapid loss of apatite occurred in conjunction with the formation of new uranium phosphate minerals. There was a tendency toward more stable solids with time, ending with metaautunite in the acidic system. Electron optical analysis by both scanning and transmission electron microscopes equipped with an EDX microprobe confirmed the association of uranium with phosphate and that uranium was not associated with apatite, precluding a simple adsorption reaction. Column Hydrodynamics Bromide breakthrough curves show a conservative behavior of bromide, i.e., the breakthrough occurs at one pore volume of outflow. For Column 2, there appears to be a slight physical non-equilibrium present, indicated by the deviation of the measured data from the model calculations between one and five pore volumes. This physical non-equilibrium is likely the result of stagnant fluid inside the column, presumably caused by non-homogeneous packing of the apatite material. Both flow rates used result in relatively high Peclet numbers, Pe=98 for Column 1 and Pe=123 for Column 2. Uranium Transport Uranium concentrations have been periodically measured in the column outflow. However, during the entire course of the experiment, no detectable levels of uranium have been observed. Column outflow remained free of uranium after 1,400 pore volumes of flow through Column 1 and after 9,998 pore volumes in Column 2. In both columns, uranium migrated only a few centimeters within the columns. The depth profiles show that the main mass of uranium was immobilized within the first centimeter of the columns, no front migration of uranium was observed. The maximum penetration depths in the two columns were similar, despite the considerably larger pore volume of flow through column 2. Uranium concentrations in column 2, however, were larger than in column 1. In total, 778 mg of uranium were immobilized in column 1 compared to 346 mg in column 2. If we relate the amount of uranium immobilized to the cross-section of the columns, we obtain an uranium retention of 153 mg cm-2 in column 1 and 899 mg cm-2 in column 2. As the penetration distances are similar between the columns, we conclude that the capacity of uranium immobilization by apatite has not been reached yet in either of the columns. Uranium penetrated to a depth of about 4 cm in both columns, but as mentioned above, it appears that the capacity for uranium immobilization has not been reached in either of the columns. From this we can conclude that apatite is very effective in removing uranium from the solution phase. Conclusions Apatite has been shown to be very effective to remove soluble uranium from the liquid phase. No uranium breakthrough has been observed in the two apatite columns after about 1,600 and 10,000 pore volumes of flow through the columns, corresponding to 270 and 180 days at the specific flow rates, respectively. Sectioning of the column and EDXS analyses revealed that uranium was associated with the solid phase, likely forming a uranium-phosphate mineral such as autunite (Ca(UO2)2(PO4)2), although the specific form of the uranium precipitate has not been identified in this study. The capacity of uranium precipitation in the top of the columns has not been reached during the experiments. Therefore the quantitative magnitude of uranium immobilization cannot be determined with the available data. All we can conclude is that the capacity of the apatite to immobilize uranium per cross-sectional area is much larger than 899 mg/cm2 for the first 4 cm of the apatite columns. This corresponds to 144 mg uranium per gram of apatite (899b/4 = 144 mg/g). Column studies should have been run for a longer period of time, but funds for doing so are not available at the moment. For additional information on this project, visit the State of Washington Water Research Center website at http://www.wsu.edu.swwrc/ under the heading Research Projects.

Descriptors

Contaminant Transport, Groundwater Quality, Pollutants, Mining, Solute Transport

Articles in Refereed Scientific Journals

Book Chapters

Flury, M. and T. Gimmi, in review, Solute Diffusion, In: Dane J. and C. Topp (eds), Methods of Soil Analysis, Physical Methods, American Society of Agronomy, Madison, WI.

Dissertations

Water Resources Research Institute Reports

Flury, Markus and James B. Harsh, 2000. Remediation of uranium contaminated mine waste. State of Washington Water Research Center Report SWWRC-B-03. Pullman, Washington. 25pp.

Conference Proceedings

Other Publications

Wong, R., M. Flury, and J.B. Harsh, 2000, Remediation of Uranium Contaminated Mine Waste at the Midnite Mine, Washington, Poster Presentation. WSU Native American Advisory Board Tour of the WSU/NSF IGERT Center for Multiphase Environmental Research, April 7, 2000, Washington State University, Pullman.

Basic Project Information

Basic Project Information	
Category	**Data**
Title	Mechanisms of Pesticide Transport to Surface Water at the Field Scale in a Dryland-Agriculture Region
Project Number	B-01
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Ground-water Flow and Transport
Focus Category #1	Solute Transport
Focus Category #2	Hydrology
Focus Category #3	Water Quality
Lead Institution	Washington State University

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Richelle Allen-King	Assistant Professor	Washington State University	01
C. Kent Keller	Associate Professor	Washington State University	02
John Schaumloffel	Unknown	Washington State University	03

Problem and Research Objectives

The occurrence of pesticides in surface waters is in part a consequence of increased chemical usage to improve agricultural productivity over the past approximately 50 years. Pesticides can be relatively mobile when suspended in stream or river flow. Transport downstream and dispersion within the reservoirs of the hydrologic cycle result in the potential to affect both human and environmental health over a relatively wide area. Potential processes affecting pesticide migration after application to an agricultural field include: surface runoff, leaching in the aqueous phase, sorption onto mobile or immobile soil particles and colloids, volatilization into the atmosphere, abiotic and biotic transformations, photodecomposition, and uptake by target and non-target flora and fauna 9). Surface and subsurface transport are the dominant mechanisms causing surface and ground water quality degradation. Pesticide concentrations exceeding published water quality standards have been detected in the Palouse River at a point which provides integrated, basin-scale information about this dryland agriculture region. For example, triallate (trade name Far-Go), the pesticide with the largest active ingredient application rate in the region, was detected in the Palouse River by U.S. Geological Survey (USGS) scientists at concentrations that seasonally exceeded the freshwater-chronic criteria for the protection of aquatic life of 0.24 µg/L. The Palouse River drains a semi-arid portion of the Columbia Plateau that is characterized by dryland wheat and pea agriculture and soil formed in loess parent material. The Palouse River is the main outflow pathway for surficial water in the Palouse Drainage Basin, which measures approximately 2,500 square miles and empties into the Snake River, which is widely used for recreational purposes and drains into the Pacific Ocean. While these data demonstrate that triallate, an herbicide used extensively in the Palouse region of Washington state, is present in surface water, no studies in the region exist which provide information about the pathways by which triallate or other herbicides enter the surface water. Few studies on the fate of this chemical at the field-scale have been conducted in any region - none have been conducted in the Palouse region. Without information about transport pathways at the field-scale, solutions to reduce surface water concentrations cannot be determined. The goal of this study was to determine the importance of local-scale (field-scale) subsurface transport as a pathway for pesticide migration to surface water in the Palouse region, a dryland agriculture area. The approach taken quantified total pesticide discharge at the field scale following a spring application of the target pesticide, triallate, to a tile-drained field. Triallate was selected as the target analyte because: it is a moderately volatile and hydrophobic organic compound, properties common to other pesticides used for agricultural purposes; it has a high application rate in the area; and, it has been identified at relatively high concentrations in the basin-scale discharge.

Methodology

Field Setting and Instrumentation The non-irrigated field site used to gather environmental data for the project is located about 15 miles south of Pullman, WA at T.14N. R.44E. Sect.25. Annual precipitation for the semi-arid environment is 31-58 cm/yr, and the recharge rates are 0.9-8 cm/yr. The geologic setting is very typical of the Palouse region, consisting of wind blown loess deposited over basalt. The soil profile is classified as a fine-silty, mixed, mesic Xeric Argialboll under the Latah Series and formed in alluvium from loess and volcanic ash. The loess dunes surrounding the field site form a basin, such that there is only one outflow pathway for shallow flowing ground water and overland flow to follow. The physical soil characteristics of the field site are typical for Latah Series. The slope is nearly level and is located in the bottomlands, where flooding can occur from December to April. A tile drain, already placed 92cm bgs at the field site, prevents the otherwise poorly drained soil from being inundated during the planting and growing season. The field site is owned by a local, private farmer and is located on a 16 ha, non-irrigated, agricultural field within the previously described loess dune basin. The field has been used to grow winter wheat, spring wheat, and lentils on an annual rotation, and Far-Go was last sprayed onto the field in the spring of 1996. Application of Far-Go onto the field area between the lysimeter trench and the drainage ditch occurred in the autumn of 1998. On 30 April 1999 the field was sprayed with a 0.21 L/ha-2.34 L/ha-0.47 L/ha (2.9 oz/A-1 qt/A-0.4 pt/A) Pursuit-Far-Go-Sonalin HFP (trademarks American Cyanamid Company, Monsanto, Inc., and Dow AgroSciences, respectively) herbicide mixture and incorporated 9 cm bgs. The following day, the field was fertilized with liquid 16-20-0-14 N-HPO3-K2O-S fertilizer (17.9 kg-N/ha) and planted with Desi garbonzo beans with a seeding rate of 90lbs/acre. The instrumented area was sprayed with the same Pursuit-Far-Go-Sonalin mixture at the same application rate on May 14, 1999 and incorporated 9 cm bgs. On May 15, 1999 the instrumented area was sprayed with 17-25-0-14 fertilizer (19.1 kg-N/ha), broadcast-seeded with the same seeding rate of Desi garbonzo beans, and the seeds were raked into the soil surface. Three liters of 1M potassium-bromide were sprayed onto the soil surface in the instrumented area (384 kg-Br/ha). On 17 October, 120-30-60-25 granular fertilizer (134.5 kg-N/ha) was applied over the 16ha field and it was seeded with winter wheat. The instrumentation was placed at the field's hydrologic outflow boundary, along the farmer's property line, and at the drainage ditch, which collects the tile drain's effluent. Within the cropped area of the field, a trench was dug to emplace 10 pan lysimeters, 4 soil temperature probes (model 105T-L, Campell Scientific, Inc.), and 5 soil moisture probes (model CS615-L, Campell Scientific, Inc.). The pan lysimeters were placed at three different depths to follow the passage of triallate through the vadose zone. The depths at which the lysimeters were inserted were determined by soil horizon boundaries and tile drain depth. Other instrumentation used to gather data on the field includes a sampling tube to the tile drain, a precipitation bucket (model TE525, Campell Scientific, Inc.), and an atmospheric temperature probe (model 105T-L, Campell Scientific, Inc.). Pan lysimeters were chosen to collect soil water samples versus other samplers (e.g. suction cup lysimeters, wick lysimeters) for several reasons. Mallawatantri found significant vertical movement of bromide and dye tracers below 3m in Palouse soils. Therefore, a lysimeter that collects soil water over a space to include macropores and soil matrix is preferred over a smaller, point sampler, which collects mostly from capillary movement of solutes. The target analyte for the study is moderately volatile; using collection devices that rely on a continuously applied vacuum to sample water could underestimate the pesticide concentration in the sample. In addition, triallate adsorbs to soil colloids and other particulate matter. For these reasons, pan lysimeters were chosen for soil water collection in this project. However, there are drawbacks to using pan lysimeters: the samplers will only function when the soil moisture is not held under tension thus they rely primarily on rain events and snowmelt for water collection; the collection jar connected to the pan cannot be removed and cleaned between samples; and passage of solutes into the lysimeter over time is averaged. These drawbacks are outweighed by the advantages to meet the goals of this project. The pan lysimeters were constructed using relatively inert materials of primarily; stainless steel, glass, PVC, viton, teflon tubing, and three brass compression fittings. These materials were used to attain the least amount of triallate loss from adsorption to sampling materials. The pan itself was made of stainless steel. A 232 cm2 sheet of stainless steel was bent to form the pan. At the deepest point in the pan a 0.64 cm x 2.54 cm stainless steel pipe was welded onto the triangular part of the pan, allowing pore water to flow into the collection jar. Over the entrance hole of the stainless steel pipe, a screen was placed to keep large soil particles and fauna from passing into the collection jar. A 19/64 inch ID PTFE tubing (Cole Parmer Instruments) connected the pan to the collection jar. The collection jar was constructed using a 250 ml, glass, mason jar, covered with a PVC plate, and sealed with a viton-rubber O-ring (McMaster Supply Co.). The compression fittings (Swadgelocks), used for tube connections, were threaded into the PVC plate and sealed with teflon tape. One fitting attached the 19/64 inch ID PTFE tube from the pan to the top of the collection jar. The other two fittings attached two 3/16 inch ID PTFE tubes (Cole Parmer Instruments) to the collection jar for sample collection and venting above the soil surface. The tile drain running through the trench was instrumented with a line for sampling the water and a pipe to measure the water level. The sampling line was constructed using 3/16 inch ID PTFE tubing (Cole Parmer Instruments). The bottom of the line was placed 1.3 cm from the bottom of the drain tile. The line was stabilized into the tile drain using a compression fitting. The pipe used to take water level measurements was placed 30.5 cm down flow from the sampling line and was constructed using 2.54 cm, 40-schedule PVC pipe. The bottom of the pipe was placed 1.3 cm from the bottom of the drain tile and secured using a metal clamping ring. Flow measurement instruments were placed at the drainage ditch. A manufacturer calibrated, 6 inch diameter, volumetric pipe weir (Thel-Mar Co.) was placed at the end of the tile drain to measure flow. Two stream gauges spaced 1.21 m apart were placed in the drainage ditch down flow from the weir to stage water and sediment levels. Field Sampling and Analysis Water samples were taken on a weekly basis during the dryer months and following rain events from the pan lysimeters and the tile drain at the trench site. In addition, samples were also taken at the pipe weir and adjacent to one of the stream gauges. During wetter portions of the year, samples were taken from 2 to 5 times a week. Each water sample was field filtered through a pre-baked (450°C for 4 hours), binder-free (0.7 mm pore size) borosilicate membrane, held in a 45 mm diameter filtration apparatus. Between each sample collection, the filter apparatus was rinsed with pesticide grade methanol (pesticide residue £10 ng/l, Fisher Scientific) and nano-pure water. Field blanks (nano-pure water sampled using the filter apparatus between samples in the field) did not contain triallate at a concentration exceeding the estimated quantitation limit. Samples for triallate analyses were sealed with TFE/silicon septa (Alltech, Inc.) and stored refrigerated until analysis. Samples for nitrate analysis were stored frozen and samples for bromide analysis were sealed and stored at ambient temperature until analysis. Triallate was analyzed using solid-phase microextraction-gas chromatography (SPME-GC) with an electron capture detector (ECD). Most of the water samples were analyzed within 1 month after collection. The presence of triallate in selected samples was confirmed by GC/MS analysis. SPME is an analytical technique that uses a gelatinous fiber made of polydimethylsiloxane (PDMS) to extract solutes from the aqueous phase, making other sample cleanup procedures unnecessary. The fiber was cleaned for 5 minutes at 200°C with continuous gas flow. After cleaning, the 100 mm PDMS SPME fiber was exposed to the aqueous phase of the heated sample (45° C) for 15 minutes while stirring, and mass was desorbed into a 200°C heated injection port of the GC. The temperature program for the GC oven was: 60°C for 0.5 min, 20°C/min. from 60° to 140°C, 11° C/min. from 140° to 233°C, and hold 233°C for 3.5 min. The ECD was heated to 325°C. Calibration was achieved using a minimum of four different concentrations prepared from a triallate standard solution (AccuStandard, Inc.). The estimated quantitation limit was 0.006 to 0.01 mg/l. The analytical relative error was estimated from check standard measurements and was usually within 10-45% of the true concentration. Water samples collected on December 10 and 16, 1999 have an analytical relative error of 60%. Bromide water analyses were conducted using an Orion ion selective electrode (Model 94-35) and sodium-chloride ionic-strength adjuster. Nitrate-N analyses were performed at a USDA-ARS research laboratory at Washington State University, Pullman, WA. They were analyzed using an Alpkem RFA 300 continuous flow analyzer with a copperized cadmium column.

Principal Findings and Significance

To our knowledge, this study provides the first field-scale evidence that can be used to evaluate the transport pathways of pesticides to surface water in the Palouse region. It also provides the first data quantifying the nitrate concentration and discharge via tile drainage. This project followed pesticide transport in the vadose zone and via a tile line from a field to the adjacent drainage ditch (which ultimately feeds the Palouse River) from a single, tile-drained field to which the chemical was applied in the spring. The field was monitored from spring through late fall. The important findings of this study follow. 1) Triallate and nitrate (converted from ammonium) applied in spring were transported to surface drainage via subsurface tile drainage lines. Because this transport was likely to have occurred via preferential flow paths under nonequilibrium conditions, the results suggest that other compounds presenting a wide variety of chemistries may follow the same transport pathways. Within the monitored time period, concentrations reaching the surface water were highest during the few weeks immediately following application. 2) The concentration and total mass discharge of triallate from the spring application on the field was not fully captured during the approximately 6 months of monitoring following application. The pesticide was present in the vadose zone pore water samples 6 months following application, showing that the pesticide remained in the soil at detectable concentrations for more than one crop year. 3) The concentration deeper in the soil zone and in the tile drain was increasing in the late fall, at the completion of the study. Fall concentrations in the deeper portion of the sampled vadose zone were greater than those observed during the spring, implying that the tile drain concentrations might have increased following the monitored time of this study. 4) For this field during the monitored period, the primary route for triallate and nitrogen to leave the field and enter the surface water was via the tile drain. There was no surface runoff from the field during the short duration of sampling and groundwater discharge to the drainage ditch is estimated to be much lower than the tile drainage. An estimate of the annual nitrate mass discharge per area of the field suggest that mass transport via tile drainage may provide a very important component of the nitrate budget to local surface waters, particularly following a typically high fall nitrogen application. 5) Because the proportion of applied triallate which left the field during the monitored period was lower than the average reported by Wagner et al. (1996) for the basin scale, the results suggest that either the timing of transport or additional transport mechanisms for triallate are important. It is recommended that future, field-scale studies address extended duration of release from fields, response to fall rather than spring application, and transport mechanisms from fields which are not tile drained. For additional information on this project, visit the State of Washington Water Research Center website at http://www.wsu.edu.swwrc/ under the heading Research Projects.

Descriptors

Agriculture, Contaminant Transport, Groundwater Hydrology, Groundwater Quality, Herbicides, Leaching, Organic Compounds, Pollutants, Rivers, Runoff, Solute Transport, Unsaturated Flow, Water Quality

Articles in Refereed Scientific Journals

Book Chapters

Dissertations

Schultheis, K.A., 2000. Mechanisms of pesticide transport to surface water at the field-scale in a dryland agricultural region. M.S. Thesis. Department of Geology, Washington State University, 117 pp.

Water Resources Research Institute Reports

Allen-King, Richelle M., Kristin A. Schultheis, John Schaumloffel, and C. Kent Keller. 2000.

Mechanisms of pesticide transport to surface water at the field-scale in a dryland agriculture region. State of Washington Water Research Center Report SWWRC-B-01. 24 pp.

Conference Proceedings

Other Publications

Schultheis, K., Allen-King, R.M., Smith, J.L., Flury, M., Schaumloffel, J. and C.K. Keller. 1999. Mechanisms of pesticide transport to surface water at the field scale in a dryland agricultural region. Geological Society of America Annual Meeting, October 25-28, 1999, Denver, CO. Schlaumloffel, J., Allen-King, R.M., and D.T. Talmage. 2000. A rapid, simplified SPME procedure for the determination of moderately hydrophobic herbicides in agricultural runoff. American Chemical Society 220th National Meeting, August, 2000, Washington, D.C.

Basic Project Information

Basic Project Information	
Category	**Data**
Title	The Role of Turbulence and Sediment Availability in Sediment Erosion Processes
Project Number	B-02
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Engineering
Focus Category #1	Sediments
Focus Category #2	Hydrology
Focus Category #3	Floods
Lead Institution	State of Washington Water Research Center

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Thanos Papanicolaou	Assistant Professor	Washington State University	01

Problem and Research Objectives

The Spokane River is a steep gradient river that flows through the City of Spokane. Large-sized sediments are eroded and transported down the river, with significant quantities deposited up-stream of the Monroe Street Hydroelectric Dam intake. The impacts are river degradation, erosive damage to equipment, and disturbance of normal intake operations. The major thrust of this study is the proposition of a new strategic plan for river restoration not based solely on qualitative assessment, but developed using quantitative analysis. This research utilizes two-dimensional hydrodynamic modeling, FESWMS, to map the flow patterns in the river. The results are used to identify and isolate areas of accelerated sediment erosion and to develop river restoration methods to control upstream erosion. Large cobble and boulder-sized sediments are eroded and subsequently transported down the Spokane

River within the study area. The impacts are riverbed degradation, erosive damage to equipment, and disturbance of normal intake operations. These sediments are deposited in the forebay area of the Monroe Street HED intake. As sediment accumulates behind the intake screens, it interferes with the normal flow of water through the intake structure. Some of the gravel particles with size less than two inches in diameter pass through the screens and cause impact and erosive damage to turbine blades. Consequently, work crews must remove the sediment, which has typically been accomplished with disruptive and costly dredging operations. Current Department of Ecology instream flow requirements for the Spokane River preclude any further use of dredging as a means of sediment removal. The goals of this study are: (i) to find alternative methods for preventing sediment accumulation at the intake structure; and (ii) to suggest remediation measures to control the sediment erosion process well upstream of the intake structure. For these purposes, a two-dimensional hydro-dynamic finite element model is employed to depict the flow velocity field within the study area and to obtain better insight about the flow patterns and possibly mechanisms triggering sediment erosion. The research utilizes the Finite Element Surface Water Modeling System (FESWMS), developed for the Federal Highway Administration, computer program to map the transcritical flow patterns within the river channel. FESWMS offers considerable advantages over other existing numerical models since it provides information about the two dimensional velocity vector and shear stress distribution for supercritical flows [3]. The use of this model allows the detection of those areas within the forebay that exhibit high local flow acceleration, which in turn results in local scour of the river bed and banks. A sediment transport model applicable to high gradient streams will be used to predict the amount of sediment transported downstream. The major thrust of this study is the proposition of a new strategic plan for river restoration not based solely on qualitative assessment, but developed using quantitative analysis. The results are used to identify and isolate areas of accelerated sediment erosion. The quantitative information outcome of this analysis will be used to evaluate optimal strategies for bedload control in the vicinity of the Monroe Street HED. The final product of this study will be the development of a river restoration technique that yields successful sediment entrapment for a variety of flow conditions. Depending on the flow conditions, channel gradient, river geomorphology, and substrate material, several alternative structures will be developed to control upstream erosion and minimize sediment deposition or passage though the intake structure.

Methodology

METHODOLOGY Historical Analysis The first step in applying restoration techniques to a serious problem in a river system is to perform a qualitative historical analysis. An historical analysis has the potential to highlight what later may seem like obvious causes of or obvious solutions to the problem. Even if the obvious solution is not reasonably attainable, it is imperative to understand the underlying mechanisms of what is causing the problem in the first place in order to develop an appropriate solution. It is important to perform this analysis even in the case where there is little documentation of what used to be the historical condition of the river system, if only to document the fact that this information was sought and not found [2]. Available documentation concerning the Spokane River and the development of the sediment issue at Monroe HED was reviewed in order to evaluate the impacts that several hydraulic and non-hydraulic structures, built along the stream corridor, had on the historically natural state of the Spokane River. FESWMS The Spokane River Restoration model consists of two components, the hydrodynamic and the sediment transport. The focus of the present study is found on the hydrodynamic component. In this investigation a two-dimensional hydrodynamic model is used to depict the flow field (i.e., velocity). The two-dimensional velocity vector will be used to determine the shear stress distribution along the longitudinal and transverse directions. This information is important to determine accurately sediment transport rates and provide solutions for stream restoration. Specifically the FESWMS version 2 model is used here. This model, developed for and sponsored by the Federal Highway Administration, is applicable to both subcritical and supercritical flow conditions [3]. FESWMS is used to compute water surface elevations and flow velocities at nodes in a finite element mesh (FEM) representing a body of water such as a river, harbor, or estuary. Both steady state and transient solutions can be determined with FESWMS, so it is possible to model static flow conditions such as a river with constant flow, or dynamic flow conditions such as river flows with hydroelectric dam flow releases. The commercially available software SMS (Surface Water Modeling System) was used to pre- and post-process the model input and output data. This software enables the user to quickly construct a finite element grid, and allows for quick and easy evaluation of the model results. To "run" FESWMS, the Finite Element Mesh (FEM) is first constructed for the reach of interest along the river. Data defining the boundary conditions and material properties are then required. FESWMS applies the finite element method to solve the system of equations that describes two-dimensional depth-averaged surface water flow in a horizontal plane (defined by the longitudinal and transverse directions). The method of weighted residuals using Galerkin weighting is applied to the governing flow equations to form the algebraic form of the finite element equations; while the Newton's iterative method is then used to solve the non-linear terms of the momentum equations [3]. The flow field is determined using the river channel bathymetry, the river's boundary conditions, and the river's resistance to flow. The upstream boundary condition used (known as the natural condition) was a specified upstream flow. The downstream boundary condition used (known as an essential boundary condition) was the corresponding downstream water surface elevation for the specified flow. The river's resistance to flow is quantified by the river channel's value for Manning's roughness coefficient n. 2.3 Spokane River Model Data The FESWMS model was applied to a portion of the Spokane River approximately 1,725 feet (about one-third mile) in length, as previously described. The data used to develop the detailed bathymetric data for the model base map was mainly derived from topographic mapping based on aerial photography of the project area. Prominent, defining features of the study area were used to determine the boundaries of the FEM. Flow data for the Spokane River were obtained from the United States Geological Survey (USGS) stream flow gaging station No. 12422500 (Spokane River at Spokane, Washington), located approximately 1 mile downstream of the Monroe Street HED. A Log-Pearson Type III hydrologic analysis of the annual peak runoff for water years (1891-1998) was performed to determine design flows for the upstream boundary condition. The normal depth corresponding to each flow was calculated using a uniform flow equation to determine the downstream boundary condition. A number of methods exist for estimating the Manning's roughness coefficient. Typically a field investigation is conducted, and the conditions encountered in the field are compared with published photographs of reaches for which n has been determined. In addition, tabular data describing reach characteristics and associated n values can be used to refine initial estimates of the roughness coefficient. For this project, field investigations were conducted during the 1999 Spring runoff period (late April and May) to visually inspect hydrologic and hydraulic conditions. Photographs taken of the channel reach in previous years during periods of low flow were also reviewed to determine river bottom and riverbank hydraulic resistance. This information was considered in conjunction with photographic comparisons and tabulated data to determine the representative n values for modeling the project study area.

Principal Findings and Significance

The first step in applying restoration techniques to a serious problem in a river system is to perform a qualitative historical analysis. An historical analysis has the potential to highlight what later may seem like obvious causes of or obvious solutions to the problem. Even if the obvious solution is not reasonably attainable, it is imperative to understand the underlying mechanisms of what is causing the problem in the first place in order to develop an appropriate solution. It is important to perform this analysis even in the case where there is little documentation of what used to be the historical condition of the river system, if only to document the fact that this information was sought and not found. Available documentation concerning the Spokane River and the development of the sediment issue at Monroe HED was reviewed in order to evaluate the impacts that several hydraulic and non-hydraulic structures, built along the stream corridor, had on the historically natural state of the Spokane River. The Spokane River Restoration model consists of two components: the hydrodynamic and the sediment transport. The focus of the present study is found on the hydrodynamic component. In this investigation a two-dimensional hydrodynamic model is used to depict the flow field (i.e., velocity). The two-dimensional velocity vector will be used to determine the shear stress distribution along the longitudinal and transverse directions. This information is important to determine accurately sediment transport rates and provide solutions for stream restoration. Specifically the FESWMS version 2 model is used here. 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The normal depth corresponding to each flow was calculated using a uniform flow equation to determine the downstream boundary condition. A number of methods exist for estimating the Manning's roughness coefficient. Typically a field investigation is conducted, and the conditions encountered in the field are compared with pub-lished photographs of reaches for which n has been determined. In addition, tabular data des-cribing reach characteristics and associated n values can be used to refine initial estimates of the roughness coefficient. For this project, field investigations were conducted during the 1999 Spring runoff period (late April and May) to visually inspect hydrologic and hydraulic condi-tions. Photographs taken of the channel reach in previous years during periods of low flow were also reviewed to determine river bottom and riverbank hydraulic resistance. This information was considered in conjunction with photographic comparisons and tabulated data to determine the representative n values for modeling the project study area. The Spokane River has historically carried a significant sediment load, predominantly bedload. Some of its current sediment load is thus part of the natural state of the river. The river was also historically a very braided channel. Many branches of the Spokane River are no longer in exis-tence due to the development in the city, which has occurred along the banks and restricted the lateral migration of the river. The gradual constriction of the river to its current state suggests that the encroachment of development has had an impact on the increased erosion and sub-sequent sediment transport. Comparing topographical maps from approximately 1915 with aerial photography and contour maps from 1983, it can be seen that the longitudinal slope of the river in the study area has remained approximately the same. However, the actual ground elevations have dropped on average 10 feet, and up to 15 feet in some locations. The areas of elevation change are mainly in the river bed around Canada Island and just downstream of the spillway (found at the Monroe street dam). This suggests that the area around Canada Island may be a source of some of the sediments being eroded and transported downstream. These design flows were chosen to represent the typical flood events that result in sediment aggradation in the Monroe forebay, and several higher return period flood event flows which have occurred historically. Table 2 shows the roughness coefficients used in the model for the different materials defined. A finite element mesh was developed for the Spokane River Model.Several elements were added to the upstream end of the mesh in order to "smooth" the elements at the inflow and to encourage model convergence. Additionally, a large artificial pond was added to the area downstream of the Monroe HED where in reality the Lower Falls are located. This subcritical region was added since FEWMS tends to prefer subcritical regions at the inflow and outflow boundaries. Since downstream of the Monroe HED is outside of the area of interest for the erosion issue, the artificial pond does not interfere with results and facilitates model conver-gence. Preliminary results for the 2-year, 10-year, 25-year, and 100-year storm event flows have been determined. Larger velocities have been observed in the southern channel around Canada Island and along several riverbank areas for all of the flows modeled. Due to the higher change in elevation found in the southern fork of Canada comparatively to the northern fork, the velocities are higher in the southern fork. Ehe velocity in the South fork is almost double in magnitude than the velocity in the North fork. Therefore, the southern fork areas will be the focus of further sediment transport modeling and restoration measures. For additional information on this project, visit the State of Washington Water Research Center website at http://www.wsu.edu.swwrc/ under the heading Research Projects.

Descriptors

Sediment Control, River Beds, Numerical Methods, Dams, Powerhouse Intake.

Articles in Refereed Scientific Journals

Papanicolaou, A. (1999). Pick-up Probability for Sediment Entrainment, Journal of Hydraulic Engineering, ASCE, Vol. 125, No. 7, p. 788. Schuyler, A. and Papanicolaou, A. (accepted). Image Analysis Technique to Track the Evolution of Sediment Clusters, Journal of Experimental Techniques, SEM.

Book Chapters

Dissertations

Water Resources Research Institute Reports

Papanicolaou, Thanos. 2000. The Role of Turbulence and Sediment Availability in Sediment Erosion Processes. State of Washington Water Research Center Report SWWRC-B-02. Pullman,

Washington.21 pp.

Conference Proceedings

Other Publications

Schuyler, A. and Papanicolaou, A. The Effects of Cluster Bedforms on the Longitudinal Velocity. Paper accepted for presentation at the 2000 ASCE Water Resources Engineering and Water Resources Planning and Management Conference, Minneapolis, MN. Peterschmidt, L. and Papanicolaou, A. Sediment Erosion Control and Restoration Measures for the Spokane River, WA. Paper accepted for presentation at the 2000 ASCE Water Resources Engineering and Water Resources Planning and Management Conference, Minneapolis, MN.

Basic Project Information

Basic Project Information	
Category	**Data**
Title	A Watershed Scale Study on No-till Farming System for Reducing Sediment Delivery
Project Number	S-02
Start Date	09/01/1999
End Date	08/31/2002
Research Category	Water Quality
Focus Category #1	Sediments
Focus Category #2	Agriculture
Focus Category #3	Models
Lead Institution	State of Washington Water Research Center

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Shulin Chen	Associate Professor	Washington State University	01
Rollin Hotchkiss	Associate Professor	Washington State University	02
Darin Saul	Unknown	Washington State University	03
Donald McCool	Unknown	US Department of Agriculture	04
James C. Ebbert	Unknown	US Geological Survey	05

Problem and Research Objectives

This project addresses priority areas of water research in the Pacific Northwest. The increased listing of salmon species as threatened or endangered by the National Marine Fisheries Service, under provisions of the Endangered Species Act, has profound impacts to agricultural practices and agriculture sustainability. The Northwest Wheat and Range Region (NWRR) has one of the highest soil erosion levels of the United States. Freezing and thawing cycles of the ground detach soil particles, making them easy to be transported by runoff. In addition, currently practiced farming systems tend to leave the soil unprotected to the rain energy. Protecting fish habitat by controlling soil loss and associated sediment and chemical loading to the streams is a major challenge to the farmers in this region. No-till farming has been recommended to farmers as a conservation culture practice to reduce soil erosion. The effectiveness of this practice, however, has not been evaluated at a watershed scale. Clearly, this project fits the RFP in the area described as "Extermination of the effectiveness of Best Management Practices (BMPs) at watershed scales of tens to hundreds of square miles". Another important soil erosion-related issue is sediment delivery. One of the questions that farmers often ask is, "what is the percentage of eroded soil that ultimately ends up in streams?" For a large area in northern Idaho, eastern Oregon and eastern Washington, which is typified by steep rolling hills and freezing and thawing winter conditions, sediment delivery ratios have not been well studied. As a result, there is a lack of basic modeling tools for the purpose of planning, management, and policy development for these agricultural watersheds. The objectives of this research are: 1. Compare soil loss from no-till and traditional farming fields 2. Evaluate models for sediment delivery process under no-till and traditional farming conditions 3. Develop a model for predicting sediment delivery of the entire watershed

Methodology

For Objective 1: Six fields (three wheat fields with conventional tillage and three wheat fields with no tillage) were selected. In each of those fields, three one-square meter runoff plots were installed for determining comparative runoff and soil loss. In addition, three runoff plots of same dimensions were installed in a forest site. Total one-square meter runoff plots were installed for this study. Total runoff was measured and sediment sample was collected from each plot every other week from November 1999 to March 2000. From the sample, total solids concentration was determined in the WSU Water Quality Laboratory. For Objective 2: This objective will be addressed from next season For Objective 3: An overland flow model and a sediment transport model are currently being developed for a subwatershed located near Pomeroy. From this model, sediment delivery to a main channel will be predicted. The subwatershed has 183 hectares. In order to develop and validate the models, the following data started to be collected last season: · Flow sequence in response to a storm; by an ultrasonic sensor placed into a culvert located in the main channel of the subwatershed. · Rainfall intensity sequence; by a recording rain gage. · Infiltration sequence; by taking the difference between rainfall and flow in the runoff plots. · Sediment production sequence (transported by main channel): by a mechanic al sampler. A process - based hydrologic modeling framework using Saint-Venant equations has been developed. Saint-Venant equations include a continuity equation and a momentum equation. In the case of the NWRR, with low precipitation intensities, the momentum equation is replaced by the Chezy equation. The sediment transport model will be developed based on rill and interrill physical processes. Simulated rainfall will be used to derive equations for rill formation and sediment transport.

Principal Findings and Significance

Objective 1: Runoff produced in the 21 plots of all the wheat fields was about 18 percent of the total fallen precipitation. The rest of the water is considered as infiltrated. The relatively small runoff produced could be due to the fact that most of the precipitation was as snow, with a long period of accumulation. Freezing was observed to cause soil cracking, enhancing infiltration of water while the snow was melting. In only one pair of fields there was a significant higher level of runoff in a conventional tillage field relative to the no-till wheat field. This difference was in the fields that comparatively registered lesser precipitation amounts, which could indicate a better absorption of water by no-till residues within certain precipitation amounts. Total solids concentrations in runoff were generally higher in conventional tillage fields, so as the total amounts of solids. This fact reveals that the soil erosion is effectively reduced by no-till practice, even though the runoff differences between cropping practices were not evident. In only one pair of areas, the no-till practice showed more erosion than the conventional one. However, field observations indicated higher amounts of soil detachment and movement in the conventional field. Objective 3: Validation and a full development of the hydrologic and sediment model will be postponed due to the lack of data. Reduced number of precipitation events during the last winter caused did not produce significant hydrologic response of the subwatershed and practically no delivery of sediments to the main channel. For additional information on this project, visit the State of Washington Water Research Center website at http://www.wsu.edu.swwrc/ under the heading Research Projects.

Descriptors

Sediment delivery, best management practice, watershed, soil erosion, water quality, watershed management, runoff, conservation farming

Articles in Refereed Scientific Journals

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Other Publications

Basic Project Information

Basic Project Information	
Category	**Data**
Title	Surface and Subsurface Transport Pathways of Non-point Agricultural Pollutants:colon; Analysis of the Problem Over Four Decades of Basin Scale
Project Number	S-01
Start Date	09/01/1999
End Date	05/31/2002
Research Category	Water Quality
Focus Category #1	Non Point Pollution

Category #1	
Focus Category #2	Nitrate Contamination
Focus Category #3	Groundwater
Lead Institution	State of Washington Water Research Center

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Richelle Allen-King	Associate Professor	Washington State University	01
C. Kent Keller	Associate Professor	Washington State University	02
Michael Barber	Associate Professor	Washington State University	03
Markus Flury	Assistant Professor	Washington State University	04
Jeffrey L. Smith	Unknown	US Department of Agriculture	05

Problem and Research Objectives

The overarching goal of the proposed research is to understand the contributions of surface and subsurface hydrologic components to non-point chemical loading of surface water, at field and basin scales, in a semi-arid dryland agricultural setting. An important contribution of this study is that it will use geochemical tracers (including stable isotopes) to quantify the sources of water discharge at multiple watershed scales. This work will build on previous and on-going, primarily basin-scale study, conducted by USGS researchers as part of the NAWQA program. It will be of use to USGS researchers in assessing methodologies for scale-up from field to large-basin watershed area. The improved understanding of hydrologic transport pathways gained will be used to assess the impact of current agricultural practices on the chemical loading of the shallow groundwater system. The specific objectives of the study are: 1. to quantify field-scale occurrence and movement of an herbicide (triallate) and a nutrient (nitrate) at selected field-sites and concurrently trace transmission to local drainage ways; 2. to separate hydrographs of local- to basin-scale surface-water flows into their overland, soil-water, and groundwater components, using measured compositions of multiple, independent chemical and isotopic tracers (TDS, SiO2, Cl, 18O); 3. to test the ability of the resultant models to explain observed nitrate and triallate concentrations in surface water associated with each scale; 4. to use the understanding gained to estimate the effects of non-point chemical application on the shallow groundwater resource at field and basin scales. These objectives will be met through the analysis of triallate and nitrate concentrations and water discharges in surface runoff, soil solution, groundwater, tile drain water and concurrent drainage for two particular fields. 'Upscaling' of the mixing model relationships developed at the field scale will be tested through monitoring of discharge at watershed scales up to the river-basin scale (6.5×105 ha) at regular intervals over a water year. Because the study focuses on the processes that control transport, the information gained will provide insights on the fate of other chemicals with similar physicochemical properties. We anticipate that the methods developed will be useful in other basins studied in the USGS NAWQA program.

Methodology

Samples for triallate, EC (electrical conductivity), silica, nitrate and 18O determinations were collected from lysimeters installed at three depths and from surface runoff (when present) at approximately 10 day intervals. The EC is determined promptly. Samples for triallate analyses were filtered through pre-combusted 0.7 um glass fiber membranes and stored refrigerated until analysis by solid phase microextraction, gas chromatography with electron capture detection. Samples for nitrate and silica analysis were filtered a second time with a 0.2mm cellulose nitrate membrane. Samples for nitrate analyses were preserved frozen while those for silica and O18 were stored at room temperature, in the dark. Surface discharge was estimated at the time of water quality sample collection.

Principal Findings and Significance

SUMMARY OF PROGRESS TO DATE During the initial four months of this project, effort has been concentrated in three main areas: 1. recruiting students and a post doc for the project positions; 2. monitoring a previously instrumented field to provide additional baseline data to this project; 3. field selection and instrumentation procurement. We have been successful in identifying student candidates with qualifications and interests that well suit the project. Two undergraduate students have become involved in field sampling this semester. We anticipate that these students will continue with the project next academic year. An MS student has been recruited to the Geology Department and we expect that she will work with us on this project. The Ph.D. and post doctoral candidates have accepted the project positions and are expected to begin work in June, 2000. The field selection process has yielded three candidate sites for detailed instrumentation. Two will be selected, contingent primarily on finalization of crop rotation. Monitoring of a field that we have previously instrumented at its outflow, using the methods described in the proposal, commenced in fall 1999. Far-Go (active ingredient triallate) was applied to a topographically-confined field (field-scale watershed) in early fall. The monitored field contrasts our prior studied location and also represents local agriculture practices in two ways: triallate was applied in fall rather than spring; the field is not tile-drained. Contrasting results between this field and the tile-drained field that was studied during Jan-Dec 1999 provides information pertinent to refining the instrument location and monitoring schedule for the coming year. Results for this aspect of the work are described below: Results to Date The triallate concentration in the ephemeral stream draining the field was very high, reaching a maximum >25 mg/L in late fall and declined slowly over the months of January and February. The maximum concentration measured was approximately two orders of magnitude greater than the aquatic standard of 0.24 mg/L (Canadian aquatic chronic standard). The ephemeral stream was intermittent during December and early January, and flowed relatively continuously following snowmelt in February through April. The observed concentrations are much greater than the concentration observed by USGS researchers in the Palouse River at Hooper during the 1993-1994 sampling season. We will be comparing concentration, duration and timing of mass discharge, and area-normalized mass-discharge between the field and River basin scales for this water year. Although the flow in the ephemeral stream is low, the high concentrations suggest that surface runoff from fields which are not tile drained may be a critical pathway for nonpoint pollutant transport to surface water in this region. Triallate infiltrated into the soil column as evidenced by the lysimeter samples. The soil pore water concentrations were much lower than detected in the ephemeral stream. Of the lysimeter samples, triallate concentrations were greatest in the shallowest samples and much lower in the deeper samples. Monitoring will continue this field season until such time as the stream and lysimeters do not produce additional water. For additional information on this project, visit the State of Washington Water Research Center website at http://www.wsu.edu.swwrc/ under the heading Research Projects.

Descriptors

Agriculture, Contaminant Transport, Fertilizers, Groundwater Hydrology, Groundwater Quality, Herbicides, Isotopes, Leaching, Nitrogen, Nutrients, Organic Compounds, Pollutants, Rivers, Runoff, Solute Transport, Unsaturated Flow, Water Quality

Articles in Refereed Scientific Journals

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Other Publications

Information Transfer Program

USGS Internship Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	6	N/A	N/A	8
Masters	5	7	N/A	2	14
Ph.D.	2	5	N/A	1	8
Post-Doc.	N/A	N/A	N/A	N/A	N/A
Total	9	18	N/A	3	30

Awards & Achievements

Publications from Prior Projects

Articles in Refereed Scientific Journals

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Other Publications