STOCHASTIC ESTIMATION OF GROUNDWATER RETURN FLOW AND DISSOLVED SELENIUM LOADING TO TWO REACHES OF THE ARKANSAS RIVER IN COLORADO

Title Page

Abstract

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   i. What is the method
   ii. Recorded use cases (international, domestic, Colorado)

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2. Study Region Description

   (a) Overview of the Lower Arkansas River Valley in Colorado

      i. Geographic location and limits
      ii. Description of the geology and alluvial aquifer and its connection to the stream system
      iii. Discussion of the general hydrology of the LARV
      iv. Discuss current land use, major crops, and irrigation practices
      v. Irrigation flows induce high concentrations of salt, Se, U, and nutrients
      vi. Sources of Se in the LARV and how irrigation practices affect the mobilization of Se from sources

   (b) Upstream Study Reach and Surrounding Region

      i. Geographic location and limits
      ii. Study reach segmentation
      iii. Description of canals, tribs, drains
      iv. Location of existing stream gauges
      v. Location and description of surface water quality sampling sites
      vi. Location and description of river cross section survey sites

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4. Evaluation of NPS Return Flow to the River Using a Water Balance Model

(a) Flow Balance Model Applied to the LARV

$Q_U = \frac{\Delta S}{\Delta t} - Q_{Surface} - Q_{Atmosphere}$ – for each Δt

i. Describe derivation of equation from 'standard' equation

ii. Justify use of the equation in this form

iii. Define Q_U constituents

(b) Stochastic and Deterministic Models

i. Define uncertainty and it's sources

ii. Define true value vs measured value

iii. Define univariate probability distributions as estimate description of an uncertainty parameter

iv. Define parametric and non-parametric distribution and their uses

(c) River Storage Change

$\frac{\Delta S}{\Delta t}$

i. define the time step

ii. define calculation of storage change

$\Delta S = \frac{y_2 - y_1}{2} \cdot \frac{Tw_1 + Tw_2}{2}$ (as the area of trapezoid)

iii. define flow depth (y) from stream gauge height (h)

A. present source document defining stream gauge height uncertainty

B. describe stream gauge height pre-defined parametric univariate uncertainty

iv. define calculation of flow depth from stream gauge height based on survey data

A. define uncertainty of flow depth vs. stream gauge height relationship. Based on personal observations.

B. present river segment flow depth results - tables and graphs

v. define calculation of top width from flow depth ($Tw = \beta_1 y^{\beta_2}$)

A. define non-linear regression used to estimate β_1 and β_2

B. describe residuals as model uncertainty

C. define method of determining parametric univariate uncertainty distribution from regression residuals

D. define distribution goodness-of-fit and tests (i.e. A-D, K-S, and visual)

E. test non-linear regression uncertainty distribution against original data

F. define distributions of β_1 and β_2

G. test uncertainty distributions against original data

H. present β_1 and β_2 uncertainty distributions - tables and graphs

I. analysis and comments on distributions

vi. present river segment $\frac{\Delta S}{\Delta t}$ results - tables and graphs

vii. present river reach $\frac{\Delta S}{\Delta t}$ results - tables and graphs

viii. analysis and comments on segment and reach results

(d) <u>Gauged Stream Flows and Diverted Canal Flows</u>

$Q_{Surface} = Q_{US} - QDS + Qin - Q_{out}$

i. Define the variables - which flow variable belongs to which Q.

ii. Define the reported flow rate uncertainty distribution - for each flow variable

A. USGS and CDWR defined uncertainty

iii. present Q results for each source/sink - tables and graphs

iv. present river segment $Q_{Surface}$ results - tables and graphs

v. present river reach $Q_{Surface}$ results - tables and graphs

vi. analysis and comments on segment and reach results

(e) <u>Atmospheric Contributions to Flow Balance</u>

$Q_{Atmosphere} = Q_P - QE$

i. Define relationship between total E and ET(ref) ($E = ET_{ref} \cdot A_{river\ surface}$)

ii. Define how to convert reported ET(ref) to Evap

A. define the uncertainty distribution of ET(ref) as per Dr. Chavez

B. define the uncertainty distributions of the additional variables used to convert from ET(ref) to E

iii. Define river surface area

A. State the use of Tw from water storage calculations

B. State the use of the same uncertainty used in water storage calculations

iv. present river segment total E results - tables and graphs

v. present river reach total E results - tables and graphs

vi. define relationship between P measured at weather stations and P realized on the river's surface

vii. define the uncertainty of measured P values

viii. present river segment P results - tables and graphs

ix. present river reach P results - tables and graphs

x. present river segment $Q_{Atmosphere}$ results - tables and graphs

xi. present river reach $Q_{Atmosphere}$ results - tables and graphs

xii. analysis and comments on segment and reach results

(f) Results of Calculated Unaccounted for Return Flows

i. Present river segment Q_U results - tables and graphs

ii. Present river reach Q_U results - tables and graphs

iii. analysis and comments on segment and reach results

5. Evaluation of NPS Selenium Loading to the River Using a Mass Balance Model

(a) Mass balance model applied to the LARV

$\dot{M}_U = \frac{\delta M_S}{\Delta t} - \dot{M}_{Surface}$

i. Describe derivation of equation from standard flow balance equation and $\dot{M} = QC$

ii. Justify use of the equation in this form

iii. Define $\dot{M}_U$ constituents

(b) Mass Storage Change

$\frac{\Delta M_S}{\Delta t}$

i. Define the time step

ii. Define relationship between water storage change and mass storage change

iii. Solute concentration models

A. define points/locations where C_{Se} is calculated

B. define linear regression (ordinary least squares)

C. define independent variables used

D. method used to optimize models

E. test optimized models

F. presentation of optimized models - tables and graphs

iv. Describing uncertainty distributions

A. describe residuals as linear regression uncertainty

B. distribution forms tested

C. method used to determine best fit (goodness-of-fit)

D. test best fit distributions

E. presentation of best fit C_{Se} distributions of residuals

v. Uncertainty of lab C_{Se} values

A. Define the uncertainty constituents

B. Data source

C. Calculation method

D. Test distribution

E. presentation of best fit lab C_{Se} uncertainty distribution

vi. Mass Storage Change Results

A. present river sement $\frac{\Delta M_S}{\Delta t}$ results - tables and graphs

B. present river reach $\frac{\Delta M_S}{\Delta t}$ results - tables and graphs

C. analysis and comments on river segment and reach results

(c) Mass Transport in Gauged Streams and Diverted Canals

$\dot{M}_{Surface} = \dot{M}_{US} - \dot{DS}_{out} + \dot{M}_{in} - \dot{M}_{out}$

i. Define the relationship between $Q_{Surface}$ and $\dot{M}_{Surface}$

ii. State which solute concentration models used with which gauged flows

iii. Present source/sink $\dot{M}$ results - tables and graphs

iv. Present river segment $\dot{M}$ results - tables and graphs

v. Present river reach $\dot{M}$ results - tables and graphs

vi. analysis and comments on river segment and reach results

(d) Results of the Calculated Unaccounted for Return Loading

i. Present river segment $\dot{M}_U$ results - tables and graphs

ii. Present river reach $\dot{M}_U$ results - tables and graphs

iii. Analysis and comments on river segment and reach results

6. Sensitivity Analysis

(a) Purpose of analysis

(b) Scope of analysis

(c) Method of analysis

i. Which variables are perturbed...by how much...and why

ii. State use of only the deterministic models for analysis

(d) Present analysis results - tables

(e) Analysis and comments on analysis results

7. Conclusion and Recommendations

(a) Unaccounted for return flow conclusions as supported by results

(b) Unaccounted for return loading conclusions as supported by results

(c) Unaccounted for flow and mass transport conclusions and hypotheses

i. comparison of unaccounted for Se concentrations to observed Se concentrations in surfacewater and groundwater

ii. possible effects of bank ecology with natural remediation of Se concentrations

iii. Discuss how results can be used to guide calibration of GW flow and mass transport models

(d) Recommendations

i. additional Se samples to verify the models.

ii. Se volitalization study on the Ark

iii. Studies of Se sorption and chem. reduction in bed and bank sediments

Sources cited/Bibliography

Appendicies