Cost Effective Salinity Removal Strategies in Irrigated Lands of the Upper Colorado River Basin

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INTRODUCTION

- The Colorado River Basin is currently affected from high salinity generated from both anthropogenic causes and natural geology.
- The annual salt loading of the Colorado River Basin (CRB) is around 9 million tons at the Hoover Dam, and the corresponding economic damage is estimated at 383 million dollars based on 2009 salinity concentrations.
- Generally, the Upper CRB is a major contributor of salinity, and the Lower CRB is a major user of impaired water. Therefore, the total salinity removal target of the Colorado River is aimed at the Upper CRB.
- Fifty nine 8-digit hydrologic unit code (HUC) watersheds in the Upper CRB are considered responsible for salinity.

- In this research, cost effective salinity allocation strategy is proposed by cost minimizing optimization.
- The objective function is formulated by using a salinity control cost function that was derived by regression analysis of salinity control amounts and the corresponding control costs from the existing salinity control units.
- Salinity removal by irrigated lands is only considered in this research assuming that maximum salinity removal in the Upper CRB can be obtained by entire retirement of irrigated lands.
- Salinity generation after retirement can be considered as salinity from natural sources. In addition, the maximum possible salinity removal from each watershed cannot exceed the differences between the current salinity loading and the projected salinity loading when irrigated lands are retired.

- Fifty four watersheds that have irrigated lands are used in cost minimizing optimization.
- A simple salinity load reduction method based on relative contribution from each watershed was used for comparison with the optimized allocation.
- Cost effective allocation strategies provide economically competitive solutions compared to the simple weighted allocation and shows different priorities in salinity removal of watersheds.
- The outcome and procedure of this research can be used to determine better load reduction strategies using both cost and equity as priorities.

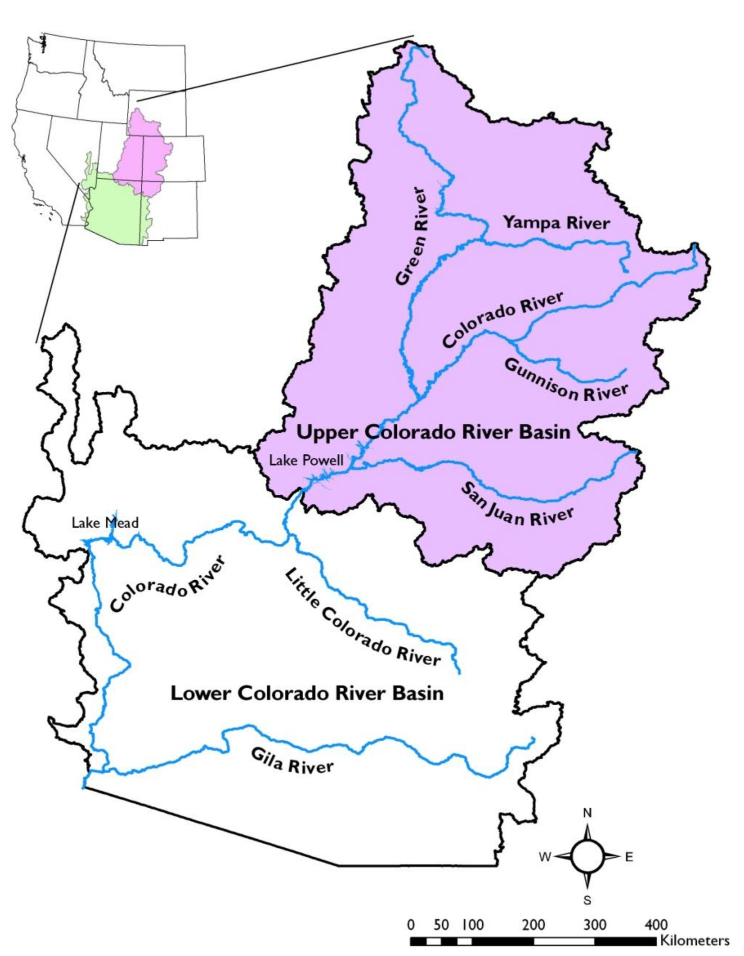
OBJECTIVES

- Develop a cost effective model in the allocation of salinity removal using cost minimizing optimization
- Compare the optimal allocation of salinity removal to the simple weighted allocation method
- Discuss the relative merits of each approach and demonstrate the need for future research

STUDY AREA

- Upper Colorado River Basin
  - Outlet : Lees Ferry, AZ (below Glen Canyon Dam)
  - Basin Area : 108,000 mi^2 (280,000 km^2)
  - Annual Precipitation : 40 inches (mostly as snow)
  - Annual Salt Loading : 9 million tons (at Hoover Dam)
  - Salinity control unit of this research : 59 watersheds in the Upper CRB

Colorado River Basin



METHODOLOGY

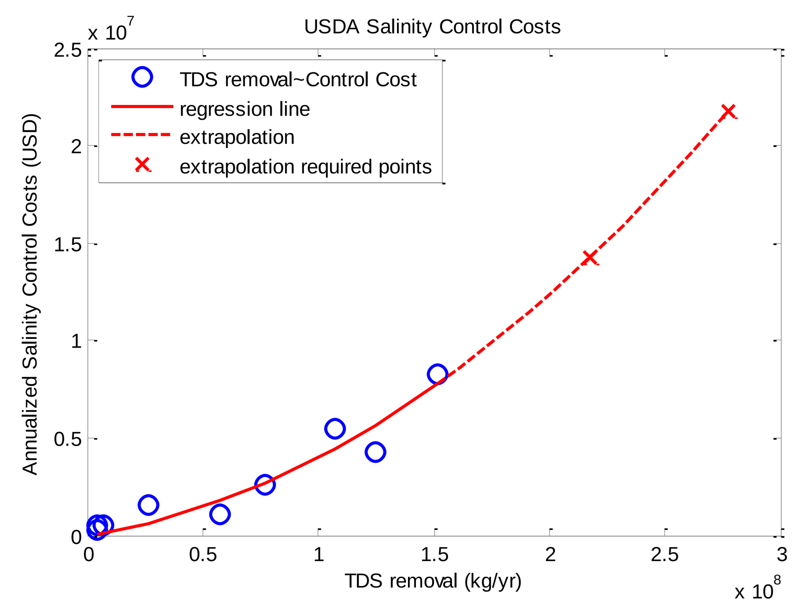
- Cost Function
  - Cost function has been established based on the control and cost relationship of existing salinity control projects.
  - USDA Salinity Control Units

    Salinity controls in irrigated lands are implemented by USDA
  - Regression analysis

    Annualized salinity control costs vs. Annual salinity control amount

$$\text{Annualized Control Cost (USD)} = 2.1676 \times 10^{-10} \times \text{TDSr}^2 + 0.0184 \times \text{TDSr}$$

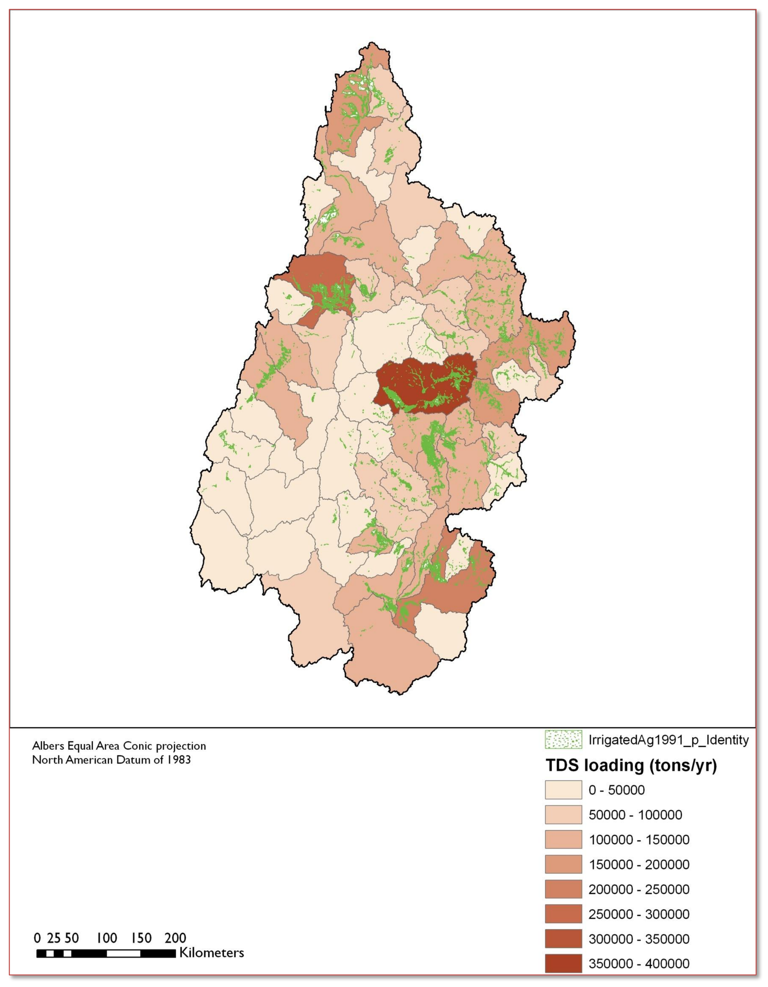
$$R^2 = 0.92$$



METHODOLOGY

- Salinity Generation Model
  - Spatially Referenced Regressions on Watershed Attributes (SPARROW) surface water quality model developed by USGS
  - Calculate instream salinity contribution (as coefficient) of each salinity source and delivery parameter
  - Coefficients estimated by Kenney and others (2007) for water year 1991 are used to calculate salinity generation

TDS loadings and irrigated lands



- Water Quality Control Target
  - Salinity control needs by 2030 = 1.85 million tons/yr

    (U. S. Department of the Interior, 2011)
  - Salinity controlled in place by 1991 = 0.27 million tons/yr

    (U. S. Department of the Interior, 1993)
  - Ratio of the salinity generation by irrigation to the total salinity generation in the CRB = 37%

    (U. S. Department of the Interior, 2011)
  - Control target = $(1.85-0.27)\times10^6\times37\%$ =584,000 tons/yr

- Scenario 1 : Simple weighted allocation

$$\text{TDSr}_i = (\text{WQ goal})_T \times \frac{(\text{irrigated land area})_i}{(\text{Total irrigated land area})_T}$$

- Scenario 2 : Cost minimizing allocation
  - Objective function : Minimize cost

$$\text{Min : C} = \sum_{i=1}^{n}(a \times \text{TDSr}_i^2 + b \times \text{TDSr}_i)$$

  - Constraints

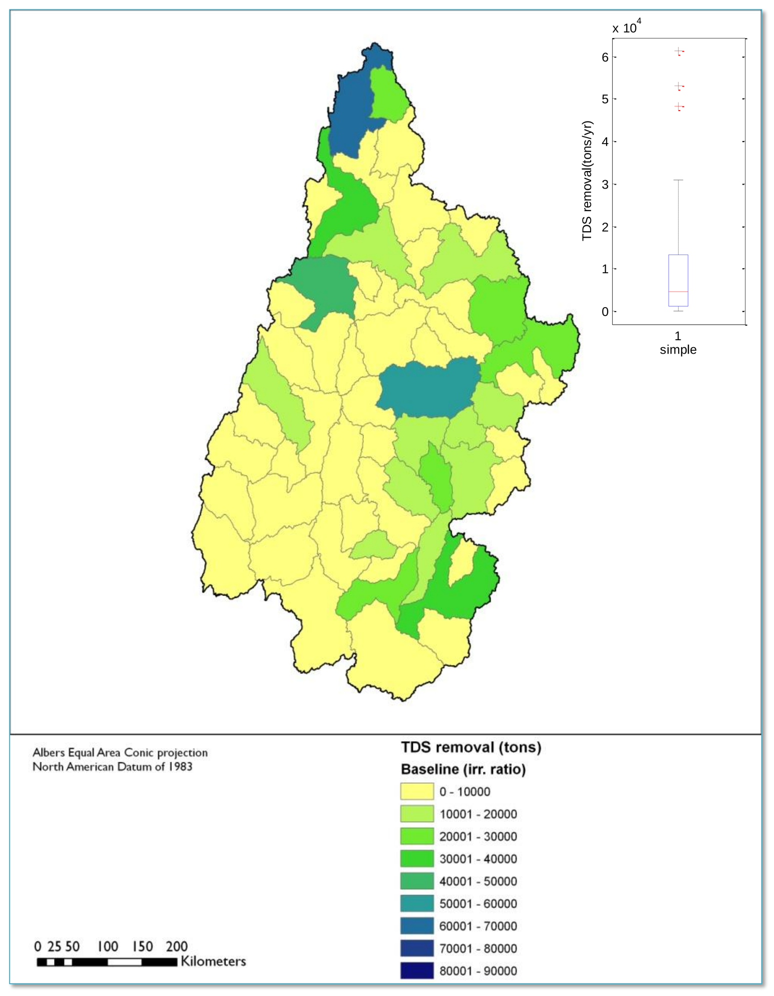
$$\text{TDSr}_i \le \text{TDSr}_{i,max}\ , \qquad \text{TDSR} \le \sum_{i=1}^{n}\text{TDSr}_i$$

  - a, b : coefficients (a=2.1676$\times10^{-10}$, b=0.0184)
  - TDSr_i : TDS removal of watershed i
  - $\text{TDSr}_{i,max}$: possible max. TDS removal of watershed i
  - TDSR : salinity control target (=584,000 tons/yr)

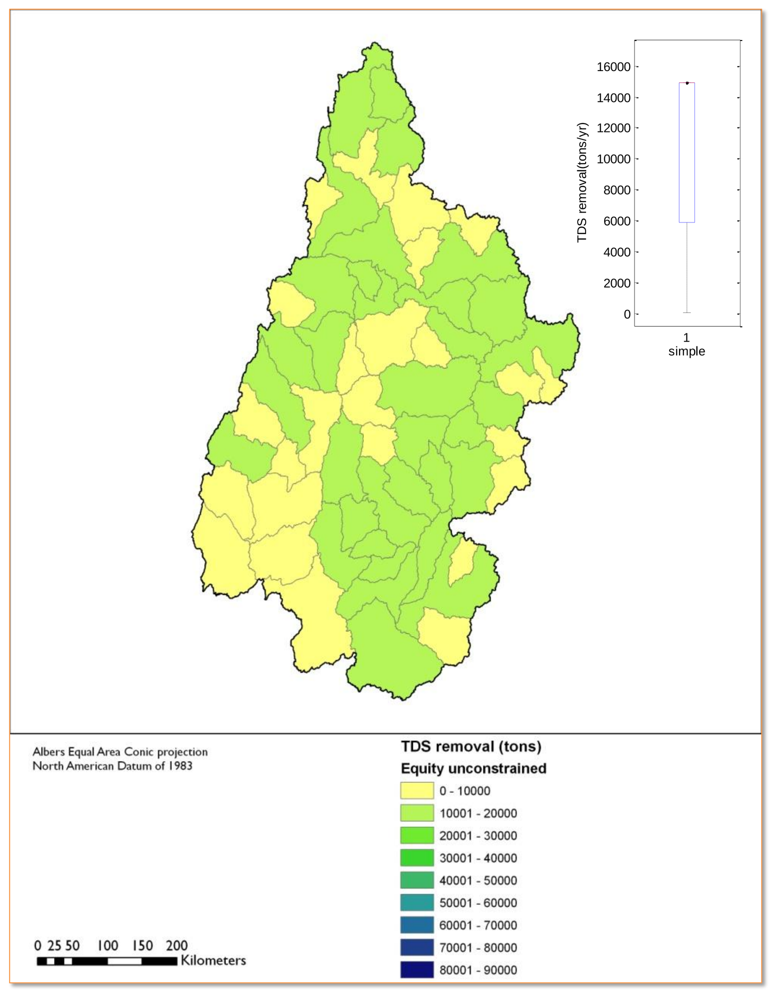
RESULTS

- Allocation of salinity control responsibilities

Simple weighted solution



Cost minimizing solution



- Total Salinity Control Cost
  - Scenario 1 (Simple weighted solution)
    - 14.52 million dollars per year
  - Scenario 2 (Cost minimizing solution)
    - 12.73 million dollars per year

- Detailed estimation of watersheds

HUC8	Scenario	14040101	14060003	14010005	14080101
TDS loading	-	183,470,380	281,638,714	389,568,596	247,761,681
Irrigated land (%)	-	9.597	8.318	6.410	4.147
$\text{TDSr}_{i,max}$ (tons/yr)	-	95,655	213,963	272,955	97,762
TDSr_i (tons/yr)	1	61,323	48,240	53,084	30,787
	2	14,935	14,935	14,935	82,132
Cost (US $/yr)	1	1,990,485	1,424,612	1,625,186	788,971
	2	329,749	329,749	329,749	3,048,367

CONCLUSIONS

- Currently, there is no scientific guidelines on prioritization of locations for cost effective salinity control in the Upper CRB.
- The commonly accepted allocation solution is the cost minimizing solution.
- Scenario 2 (cost minimizing solution) provides more cost equitable distribution among watersheds.
  - The lower control amount provides the lower marginal cost
- However, total cost minimizing solution does not consider equity of net income, irrigated land area, or availability to remove salinity of each watershed.
- Future works
  - Equitable distribution of salinity control in the Upper CRB
  - Trade-offs between equity and costs

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