RIPARIAN FORMULATION

$$0 \leq P_k \leq 1$$

for all basins, *k*

Basin proportions *Pk* are between 0 and 1.

$$A_i = P_k u_i$$

for all *i* users, in each basin *k*

Each user's allocation A_i is user *i*'s basin proportion P_k, of *i*'s demand u_i.

$$\sum_{i \in k} A_i \leq v_k - e_k$$

for all *i* users that are within each basin *k*

Mass Balance: within every basin *k*, the sum of all users' allocations are less than or equal to flow v_k in basin *k*, less any environmental instream flow requirement e_k.

$$P_j \leq P_k$$

for all basins *j* and all basins *k*

Upstream basin proportions P_i cannot exceed downstream basin proportions P_k.

$$w_k = \frac{n_i}{n_{i\ at\ basin\ outlet}}$$

for all users, *i*

A basin penalty w_k is applied that increases with the ratio of the number of users n_i upstream of basin *k*, to the number of users at the watershed outlet $n_{i\ at\ basin\ outlet}$.

Why?

- Because if upstream basins are not allowed to exceed downstream basins, then some offset is required so that downstream basins are not allocated more than upstream, to conform with the riparian doctrine of shared shared shortage.

$$\alpha < Min\left(\frac{w_k}{u_k}\right)$$

for all basins, *k*

The basin scalar α is the minimum of the ratios between downstream penalties w_k and basin-wide demands u_k.

Why?

- Because.

Objective Function:

$$\text{Minimize } z = -\sum_i A_i + \alpha \sum_k w_k P_k$$

For all users *i*, and all basins, *k*

Minimize shortage (left term) + but make the slightly modified sum of basin proportions as large as possible (right term).

APPROPRIATIVE FORMULATION

$$0 \leq A_i \leq u_i$$

for all users, *i*

Each appropriative user's allocation A_i must be between 0 and her reported demand u_i

$$\sum_{i \in k} A_{i,(appropriative)} \leq v_k - e_k - \sum_{i \in k} A_{i,(riparian)}$$

for all users *i*, in all upstream basins *k*

Mass Balance: the sum of all appropriative allocations $A_{i,appropriative}$ that are in basin *k*, must be less than or equal to available flow *vk*, less any environmental instream flow requirement e_k, less the sum of all upstream riparian allocations, $A_{i,riparian}$.

Objective Function:

$$\text{Minimize } z = \sum_i p_i (u_i - A_i)$$

for all users, *i*

Minimize the difference between demand and allocation, or shortage, ($u_i - A_i$) weighted by the inverse of the priority of user *i*.