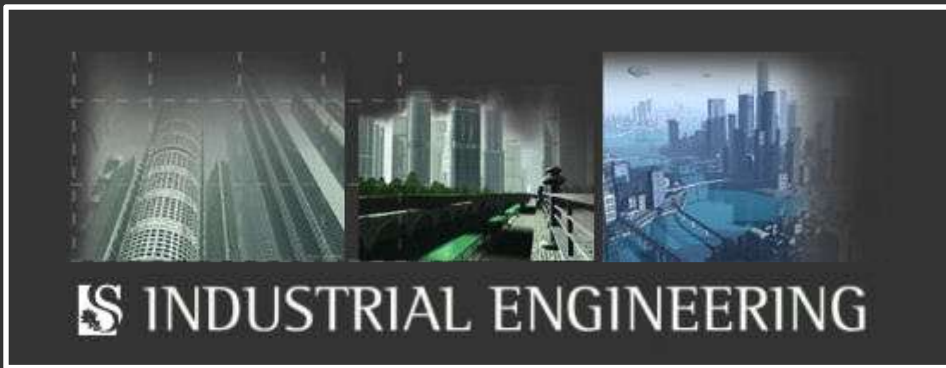

Bridging the skills gap: a tool for the development of sound catchment management strategies and water distribution plans

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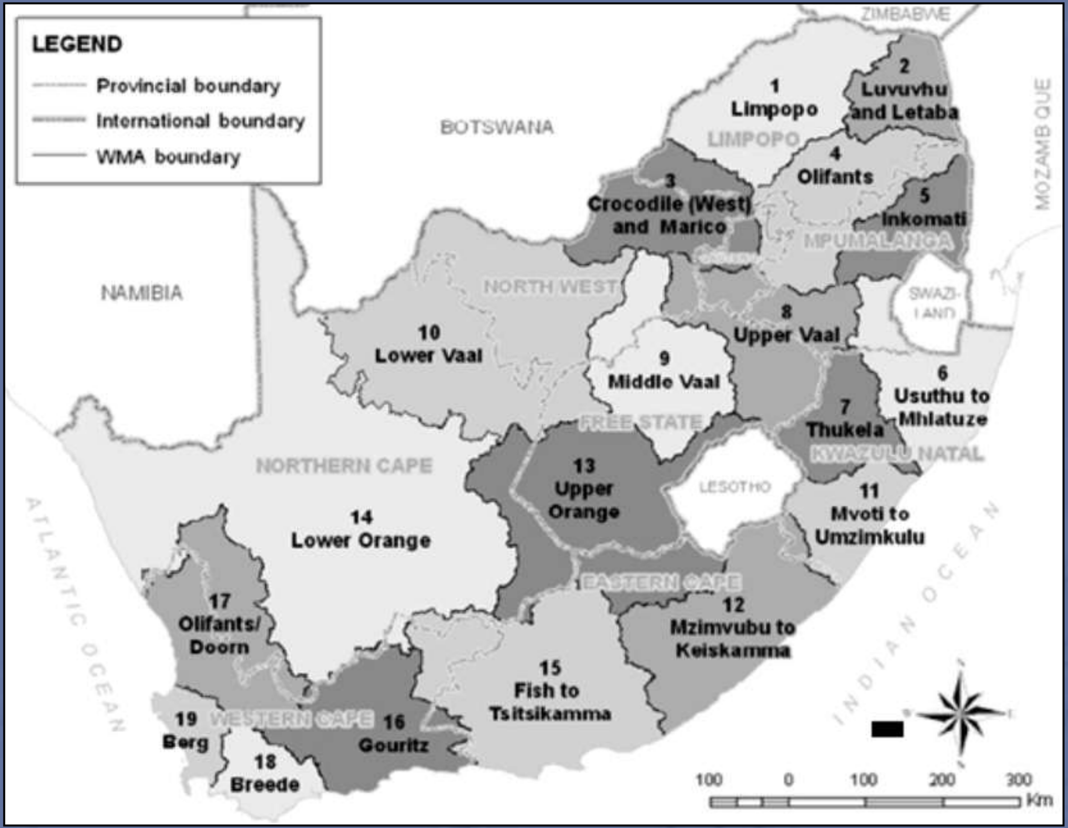
The skills gap

- In the National Water Act (Act 36 of 1998), provision was made for the creation of nineteen Catchment Management Agencies (CMAs) spanning the country.



(Nomquphu, 2007)

The skills gap

- This has subsequently been revised to 9 CMAs as the success rate of initiation is very low.
- Their main function:
  – To allocate water resources fairly amongst stakeholders

- This move has been referred to as the decentralisation of control with regards to water management.
- It has inadvertently created a skills shortage:
  – A lack of skilled personnel available to serve as Water Managers on the CMA governing boards and to develop the Catchment Management Strategies (CMSs).
  – Skills shortage in terms of translating a CMS into an actual water distribution plan.
- The question begs: how can South Africa make up for this skills gap quickly and efficiently?

The decision: water allocation

- The Water Act says:

  water is a limited and valuable resource which belongs to no single South African; rather, it belongs to all the people of South Africa.

- The goal of water management in South Africa must be to distribute it in a way which is equally beneficial to all South Africans.
- The Act clearly specifies that public participation is a critical element to achieving its goals.

The decision: water allocation

- The Human Reserve
  - water for drinking, food preparation, personal hygiene and other essential activities.

- The Ecological Reserve
  - water which is necessary to protect the ecosystems surrounding the water resource, both currently and in the future.
- The Reserve is a right to water set out in the Water Act and must be met before any other water is allocated from the resource.

The decision: water allocation

Bearing this in mind, how do you physically allocate the available water amongst the many water users who demand it?

The current approach

- The Water Priority Matrix:

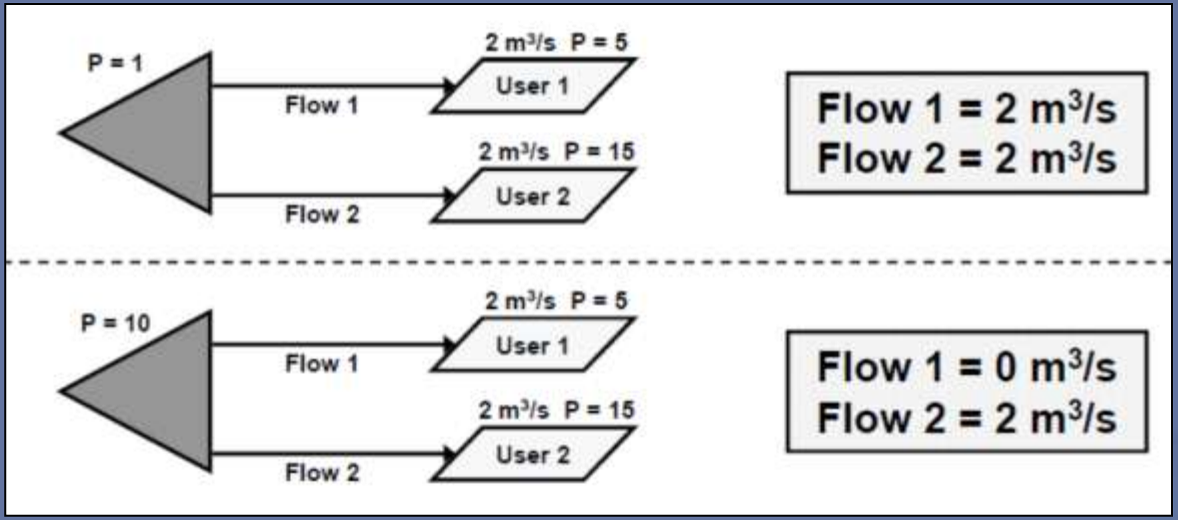
Demand distribution at required assurance of supply (%)				
User description	**Assurance of supply**			
	99.5%	**99%**	**98%**	**95%**
Losses	100	-	-	-
Wet industry	70	10	10	10
Dry Industry	70	15	5	10
Domestic	40	20	20	20
Environment	50	25	-	25
Irrigation	5	25	-	70
Priority class	*High*	*Medium high*	*Medium low*	*Low*

(Summerton, 2009)

- Helps to determine priority for water allocation, but provides no guidance on allocation volumes.
- Becomes stale and as a result outdated very easily
- Formally only demand is considered as allocation criteria

The current approach

- Decision support system based on penalty functions.
  - Allocate a penalty level for each water user
  - Applied for each unit of water desired by the user not received
  - Goal is to minimise total penalty incurred



(De Jager, 2011)

- Penalties assigned by analyst only.
- Often not considering the full scope of externalities when determining penalty levels.

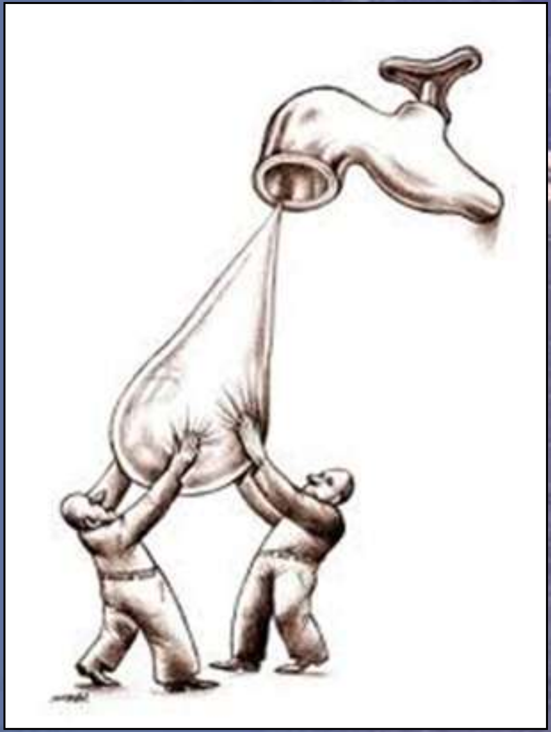
Problems with these approaches

- No fixed policy on how this decision is made.
- Allocation generally made based on the experience and expertise(?) of the authorities involved.
  - Highly subjective.
  - Often dependent on skills that don't exist.
  - He who shouts the loudest is served first. (Inequitable)
  - Not comprehensive.

- *Current water supply levels of fifteen of the nineteen WMAs are known to exceed sustainable levels.*

Specification of improved approach

- Assignment must be objective.
- Must be able to consider multiple criteria.
- Must be repeatable.
- Must require low skill levels.
- Must represent multiple stakeholders' interests fairly.



Optimisation modelling

Objective function

Subject to

Constraints

$$Max\ Z_1 = (C_{1,1}) * (W_1) + (C_{1,2}) * (W_2) + \cdots + (C_{1,n}) * (W_n)$$

$$Max\ Z_2 = (C_{2,1}) * (W_1) + (C_{2,2}) * (W_2) + \cdots + (C_{2,n}) * (W_n)$$

$$\vdots$$

$$Max\ Z_k = (C_{k,1}) * (W_1) + (C_{k,2}) * (W_2) + \cdots + (C_{k,n}) * (W_n)$$

where

$$W_j = (1.00) * (W_{j,1}) + (0.995) * (W_{j,2}) + (0.900) * (W_{j,3}) + (0.950) * (W_{j,4})$$

Subject to:

$$\sum_{j=1}^{k} \mathrm{W}_{j,a} \leq \mathrm{WMax}_a\ for\ all\ assurances\ a\ \in \{1, 2, 3, 4\}$$

$$W_{j,a} \geq 0\ for\ all\ \ water\ users\ j\ \in \{1,2, \ldots, k\}\ and\ assurances\ a \in \{1,2,3,4\}.$$

$$\sum_{a=1}^{4} W_{j,a} \leq D_j\ for\ all\ water\ users\ j\ \in \{1, 2, \ldots, k\}$$

$$\sum_{a=1}^{4} W_{j,a} \geq M_j\ for\ all\ water\ users\ j\ \in \{1, 2, \ldots, k\}$$

The objective function

$$Max\ Z_1 = (C_{1,1}) * (W_1) + (C_{1,2}) * (W_2) + \cdots + (C_{1,n}) * (W_n)$$

- Maximise BENEFIT over all users per criterion

- C_{ij} = water user performance criterion score for objective *i* and water user *j*

x

- W_j = total water allocated to water user *j*

- More water will be allocated to users scoring higher on the criterion.
- *This is repeated for each criterion.*

The objective function

- Risk (water assurance levels) not accounted for.
- Expand W_j to $W_{j,a}$

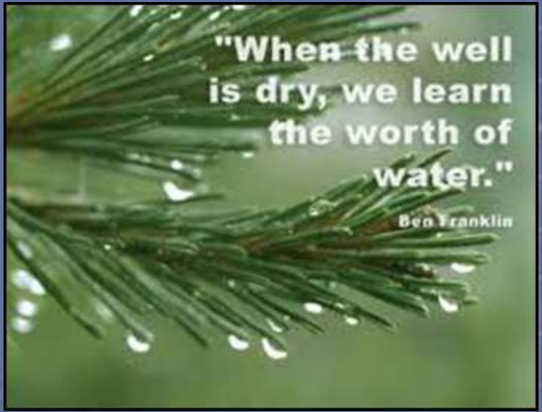
$$W_j = (1.00) * (W_{j,1}) + (0.995) * (W_{j,2}) + (0.900) * (W_{j,3}) + (0.950) * (W_{j,4})$$

- $W_{j,a}$ = water allocated to user *j* at assurance *a*

- This forces the model to allocate water at higher assurances to users who score better in terms of the proposed criteria.

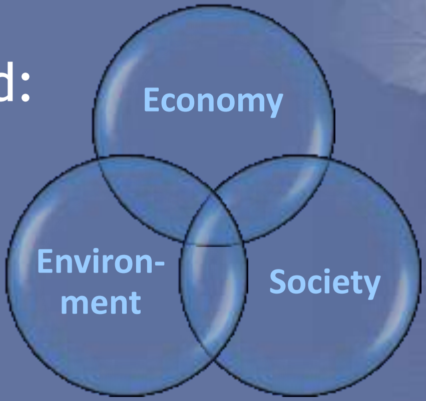
Assurance of supply

- The Water Resource Yield Model (WRYM) developed by Basson et al. (1994) is used to determine what amount of water can feasibly be drawn or abstracted from a catchment and at what level of assurance this water can be abstracted.
- Using this, a profile of the catchment can be put together showing the amount of water available at each level of assurance.



Finding C_{ij} in this study

- Not the focal point of study.
- Suggested stakeholder workshops to replace this and obtain application specific objectives.
- The triple bottom line approach adopted:



1. Economic support - economic contribution of water users to citizens of South Africa, both directly and indirectly.
2. Environmental measures - indication of how sustainable and environmentally friendly the water user is.
3. Social measures – indication of how socially responsible the water user is.

Finding C_{ij} in this study

- The Global Reporting Initiative (GRI) was established in 1997 by organisations from the Coalition for Environmentally Responsible Economies (CERES).
- From the comprehensive list of criteria put forward by the GRI, a shortlist of 26 potential criteria was compiled.
- This shortlist was presented to six leading academics in the field of sustainability:
  - Asked to select three water user performance criteria in each of the three broad categories which they deemed were most indicative of the performance of the water user.
  - Criteria had to be measurable and viable.

Finding C_{ij} in this study

Broad Field	Reference	Description	Percentage of total score
Economic Support	LA1	Total workforce size.	25%
	EC8	Economic value generated through infrastructure investments and services provided primarily for public benefit through commercial, in-kind, or pro bono engagement.	22%
	O1	Strategic importance of the water user, as defined by government.	28%
Environmental	EN9	Number of water sources significantly affected by withdrawal of water.	31%
	EN22	Total mass of waste discharged.	17%
	EN30	Total environmental protection expenditures and investments.	17%
Social	LA7	Rates of injury, occupational diseases, lost days, and absenteeism.	26%
	LA10	Average hours of training per year per employee.	21%
	SO1	Percentage of operations with implemented local community engagement, impact assessments, and development programs.	35%

The multiple objective function

- In total there are 9 criteria considered -> 9 objectives
- While these objectives may be conflicting, none of them can be neglected.
  - *It is unacceptable to allocate water such that the ecosystem surrounding a water source is irreparably damaged, even if this allocation would lead to high economic growth.*
- Each objective must be optimised separately, rather than aggregating all water user performance criteria into a single objective function.
- Each objective is treated as equally important.

Constraints

1. No more water may be allocated than is available.

$$\sum_{j=1}^{k} W_{j,a} \leq WMax_a \; for\ all\ assurances\ a \in \{1,2,3,4\}$$

2. Less than zero water cannot be allocated.

$$W_{j,a} \geq 0 \; for\ all\ water\ users\ j \in \{1,2,\ldots,k\}\ and\ assurances\ a \in \{1,2,3,4\}.$$

Constraints

3. Each water user should not be allocated more water than they desire.
   – Prohibits the algorithm from simply allocating all available water to the superior water user, even though that water user may have no use for that amount of water.

$$\sum_{a=1}^{4} W_{j,a} \leq D_j \text{ for all water users } j \in \{1, 2, \ldots, k\}$$

D_j refers to water desired by user j

Constraints

4. Each water user must be allocated at least the water specified as minimum amount.
   – Caters for compulsory water allocations, such as the *Reserve*.

$$\sum_{a=1}^{4} W_{j,a} \geq M_j \ \textit{for all water users } j \ \in \{1, 2, \ldots, k\}$$

M_j refers to the compulsory allocation to user *j*

Model output – volume/user/assurance

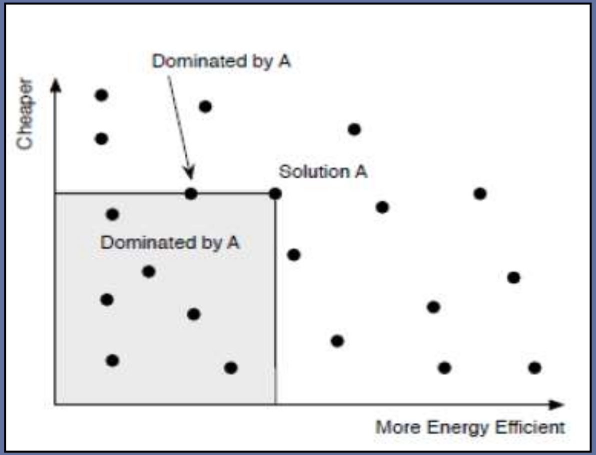
Water allocation				
Assurance	100%	99.5%	99.0%	95%
User 1	$X^{1,100\%}$	$X^{1,99.5\%}$	$X^{1,99\%}$	$X^{1,95\%}$
User 2	$X^{2,100\%}$	$X^{2,99.5\%}$	$X^{2,99\%}$	$X^{2,95\%}$
⋮	⋮	⋮	⋮	⋮
User n	$X^{n,100\%}$	$X^{n,99.5\%}$	$X^{n,99\%}$	$X^{n,95\%}$

MOO solution approach

- Exact optimisation methods generate solutions which are optimal and guaranteed.
- Approximate optimisation methods strive to generate near-optimal solutions in a practical manner, but cannot guarantee their optimality.
- Based on the variable scale and complexity of the model, approximate methods are more appropriate for this model.
- Also, when the intended user is borne in mind, approximate solvers are better suited towards stand alone software application development.
- Multi-Objective Tabu Search Algorithm used
  - by Jaeggi, Parks, Kipouros and Clarkson (2008) of the Engineering Design Centre at the University of Cambridge

Pareto dominance

- A candidate solution A is said to Pareto dominate another solution B if it is at least as good as B in terms of all objectives, and better than B in at least one objective.



(Luke, 2010)

- The Pareto-dominant set is made up of solutions each of which are not dominated by the other solutions in the set.

Model validation

- Scenario 1 is an extremely simple, two water user problem where User 1 is superior in all water user performance criteria to User 2.
- We know the demands of User 1 should be met before beginning to fulfil the demands of User 2.
- Given that the amount of water desired by User 1 is greater than the total water which is available, the best possible water allocation should involve allocating all available water to User 1.

- Results:
  - A single dominating solution was returned, rather than a set of Pareto dominant solutions.
  - The metaheuristic converged on the optimal solutions with regards to the chosen water user performance criteria in all 100 replications.

- It works!

Model implementation

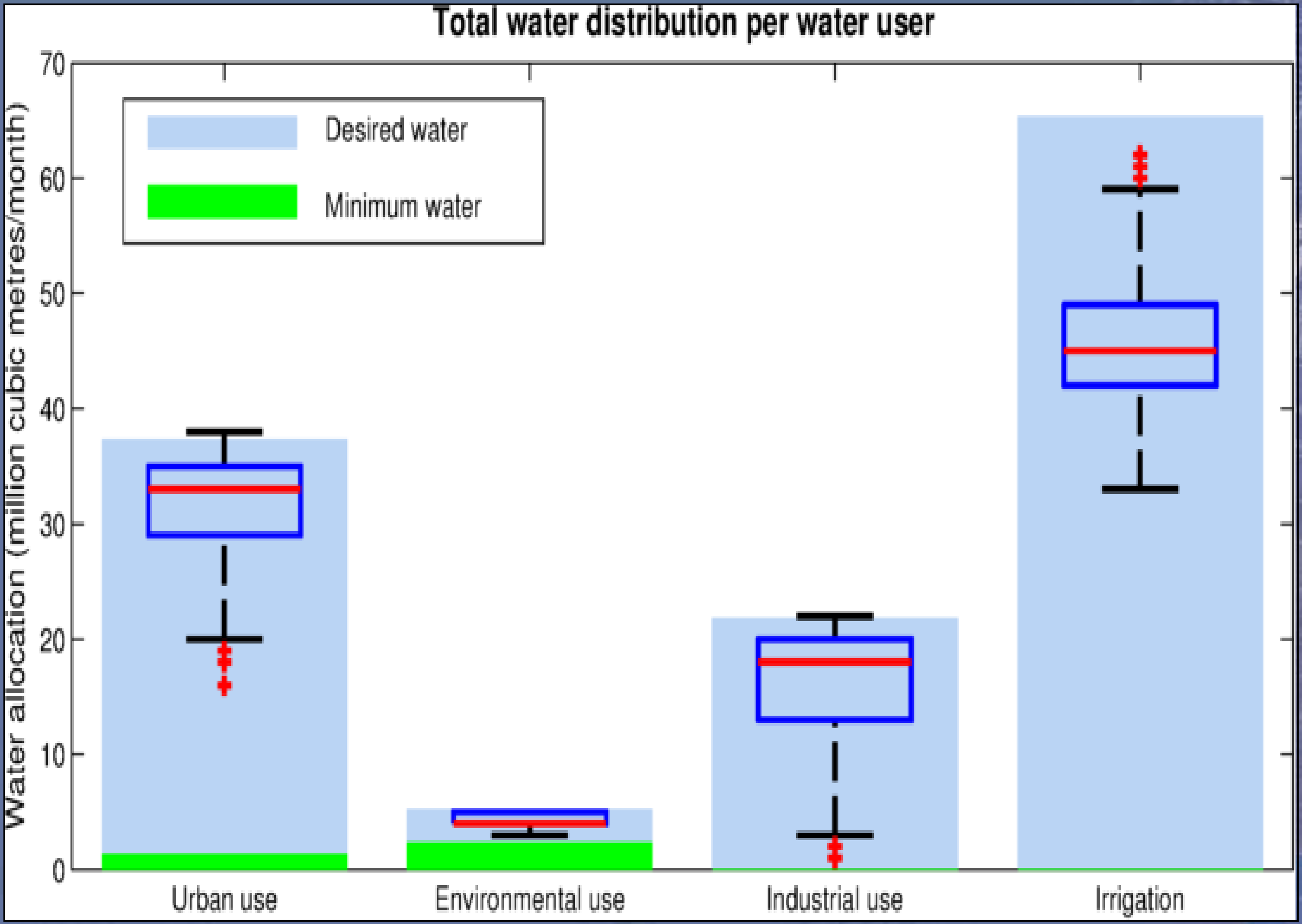
- 4 water users competing for limited water resources, none of whom clearly dominate the other users.
- Loosely based on the situation in the Mgeni catchment in KwaZulu-Natal, South Africa.

Available water (million m³/month)				
Assurance	**100%**	**99.50%**	**99.00%**	**95%**
Available Water	75.4	2.6	10.4	17.4

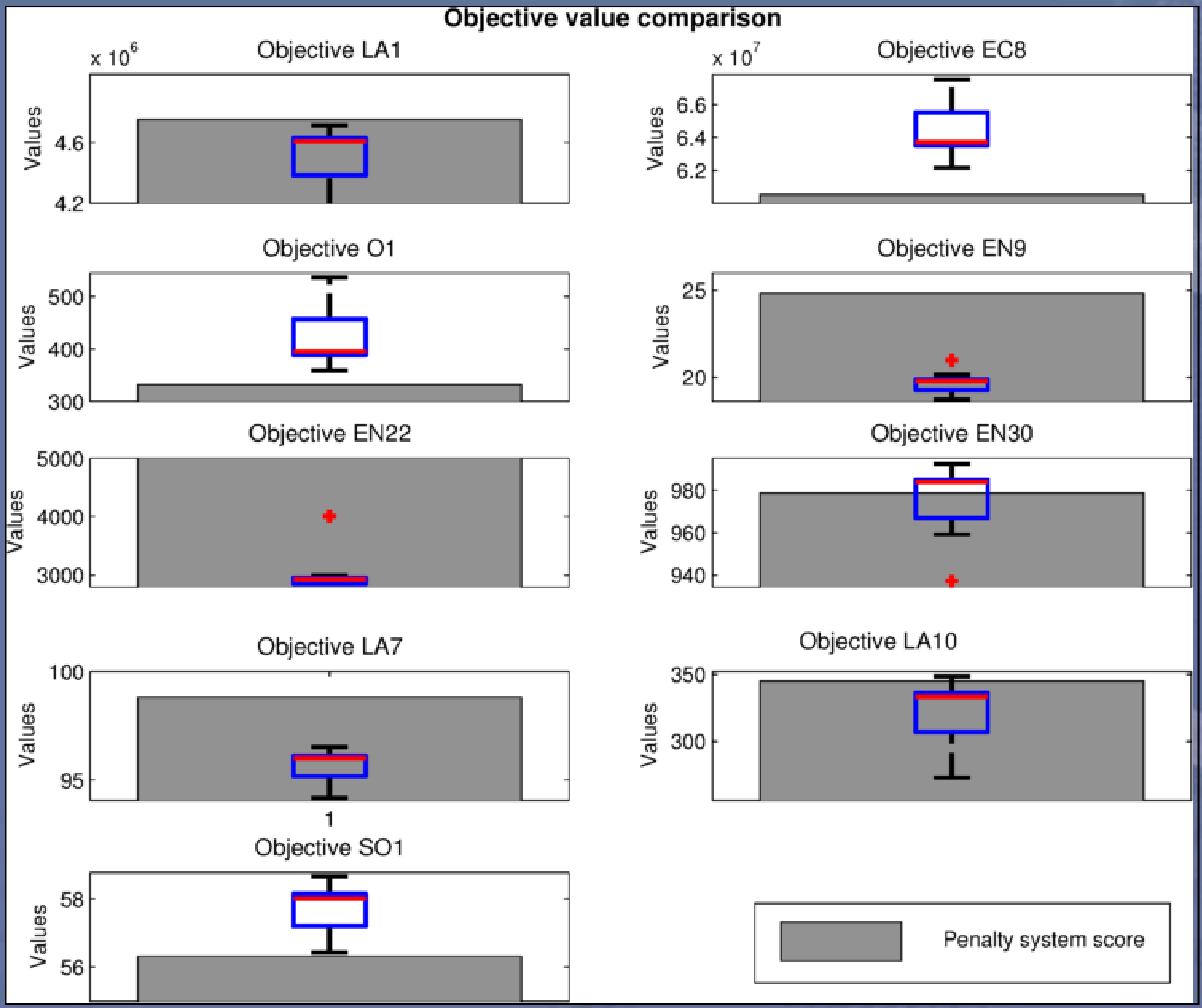
Additional constraints (million m³/month)		
	Desired Amount	**Minimum Amount**
Urban Use	37.30	1.3
Environmental Use	3.11	2.3
Industrial Use	21.77	0
Irrigation	65.32	0

Water allocation (million m³/month)				
Assurance	**100%**	**99.50%**	**99%**	**95%**
Urban Use	25	0	4	8
Environmental Use	3	0	0	0
Industrial Use	17	1	1	2
Irrigation	30	1	5	7

Results


Total water distribution per water user
Desired water
Minimum water
Water allocation (million cubic metres/month)
0
10
20
30
40
50
60
70
Urban use
Environmental use
Industrial use
Irrigation

Comparison to Penalty System



Conclusion

This project proposes a system where:

- Decisions makers look at all of the effects their decisions have.
- It encourages accountability, objectivity and repeatability of decisions.
- Decisions are based on "facts" rather than individual preferences or biases.
- Ability to emphasise job creation or other strategically important goals.
- Equitable allocation is done.
- The interface between the model and user is very simple.

MODEL SPECIFICATIONS:

- ✓ Assignment must be objective.
- ✓ Must be able to consider multiple criteria.
- ✓ Must be repeatable.
- ✓ Must require low skill levels.
- ✓ Must represent multiple stakeholders' interests fairly.

Conclusion

- This tool makes complex techniques available for use by water managers who may not have the skills or training to use these techniques themselves.
- It can thus empower these water managers to perform better.
- The participative approach in objective formulation and the model's ability to handle this complexity encourages water users to act in a responsible manner.
- It is hoped that this study can play at least a small role in guiding South Africa to a better future by improving the allocation of our scarce and limited water resources.