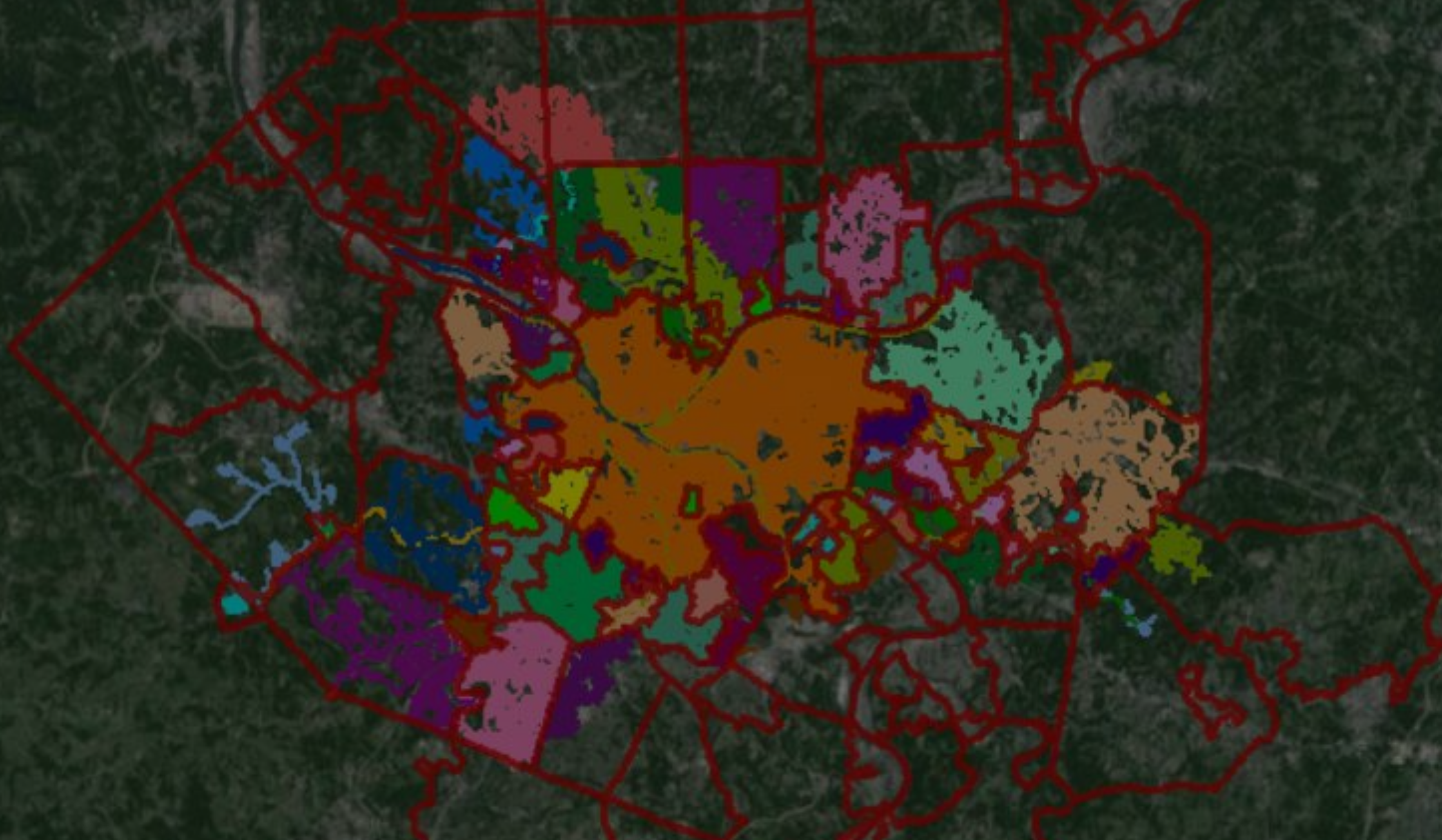
SEWERS OF THE FUTURE

evaluating regionalization alternatives for stormwater and sewer systems in Allegheny County, Pennsylvania using the Analytic Hierarchy and Network Processes



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BQOM 2521: Decision Making in Complex Environments

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INTRODUCTION

In this report – using an Analytic Hierarchy Process (AHP: Saaty 1988) and Analytic Network Process (ANP: Saaty 2001) model implemented in SuperDecisions software, version 2.2.3 – we evaluate the benefits, opportunities, costs, and risks of four alternative future paths for the communities served by the sewer and stormwater infrastructure in the Allegheny County Sanitary Authority (ALCOSAN) service area. We first briefly introduce a few of the most pertinent characteristics of the ALCOSAN service area along with some of the key issues facing the region, followed by presentation of our modeling approach, results, strengths, and limitations.

Overflows

Every year, billions of gallons of untreated sewage overflow into the Allegheny, Monongahela, and Ohio rivers, as well as a handful of larger creeks and streams throughout the Pittsburgh region (ALCOSAN 2012). In fact, in a year with typical rainfall for the region, an estimated 9 billion gallons of raw sewage, industrial wastes, and stormwater runoff – enough to fill the U.S. Steel Tower 36 times over – spill into waterways in and around Pittsburgh (ALCOSAN 2012). This is not a broken system: the sewage system serving the Pittsburgh region – like many "combined" sewer systems designed and built to serve urban areas beginning in the late 19th Century – was deliberately designed to overflow into local waterways during periods of wet weather when rainfall runoff, snowmelt, and groundwater flows overwhelm the system's conveyance capacity (Greeley & Hansen LLC 2002).

ALCOSAN

ALCOSAN serves the wastewater conveyance and treatment needs of the City of Pittsburgh and parts or all of 82 of the city's neighboring municipalities (Figure 1). In addition to the Woods Run Wastewater Treatment Plant located in the lowlands of Pittsburgh's Brighton Heights neighborhood along the banks of the Ohio River, ALCOSAN owns and operates a 90-mile network of enormous interceptor sewers buried under and along major creeks and rivers throughout the service area (Figure 2). Most of the other 4,000-plus miles of pipe networks that feed into ALOCSAN's interceptor system are owned and operated by the municipalities in which the pipes are located (Figure 1). Some municipalities have created designated authorities that own the sewage infrastructure on behalf of the municipality (e.g., the Bethel Park Municipal Authority), and a handful of municipalities in the ALCOSAN service area have banded together to create authorities that serve the wastewater conveyance and – in some instances – treatment needs of multiple municipalities (e.g., the Girty's Run Joint Sewer Authority). Regardless of instances of interjurisdictional collaboration, responsibility for sewer infrastructure operation, maintenance, and investment in the ALCOSAN service area remains highly fragmented (Figure 1, Figure 2).

Impending Abatement

Various federal, state, and local environmental protection and public health agencies have issued or entered into legal orders, agreements, and decrees to many communities throughout the country – including the communities in the ALCOSAN service area – with old, combined, overflowing sewer systems, mandating that sewer overflows be significantly abated over the next two decades. Although the path forward for the ALCOSAN service area is not yet set, despite ongoing debates about these issues over the past two decades (e.g., Environmental Law

Institute 1999, Southwestern Pennsylvania Water and Sewer Infrastructure Planning Committee 2002, Gilbert et al. 2005, Blaustein 2006, Roberts and Clark 2011, Sewer Regionalization Review Panel 2013), ALCOSAN estimates it will cost at least two billion dollars to achieve sewer overflow abatement sufficient to minimally satisfy the decrees, orders, and agreements applicable to the service area (ALCOSAN 2012), making the impending investments the most expensive public infrastructure project in the history of Allegheny County.

Future Sewers

While there are many crucial issues to be resolved in charting the future of the ALCOSAN service area, one of the most important, most-debated (e.g., Environmental Law Institute 1999, Southwestern Pennsylvania Water and Sewer Infrastructure Planning Committee 2002, Gilbert et al. 2005, Blaustein 2006, Roberts and Clark 2011, Sewer Regionalization Review Panel 2013), and foundational issues concerns how the ownership and operation responsibilities for different parts of this interconnected and interdependent system are allocated among the numerous stakeholders. As noted above, at present, infrastructure ownership and operation responsibilities are highly fragmented among the scores of municipalities, their designated authorities, and ALCOSAN.

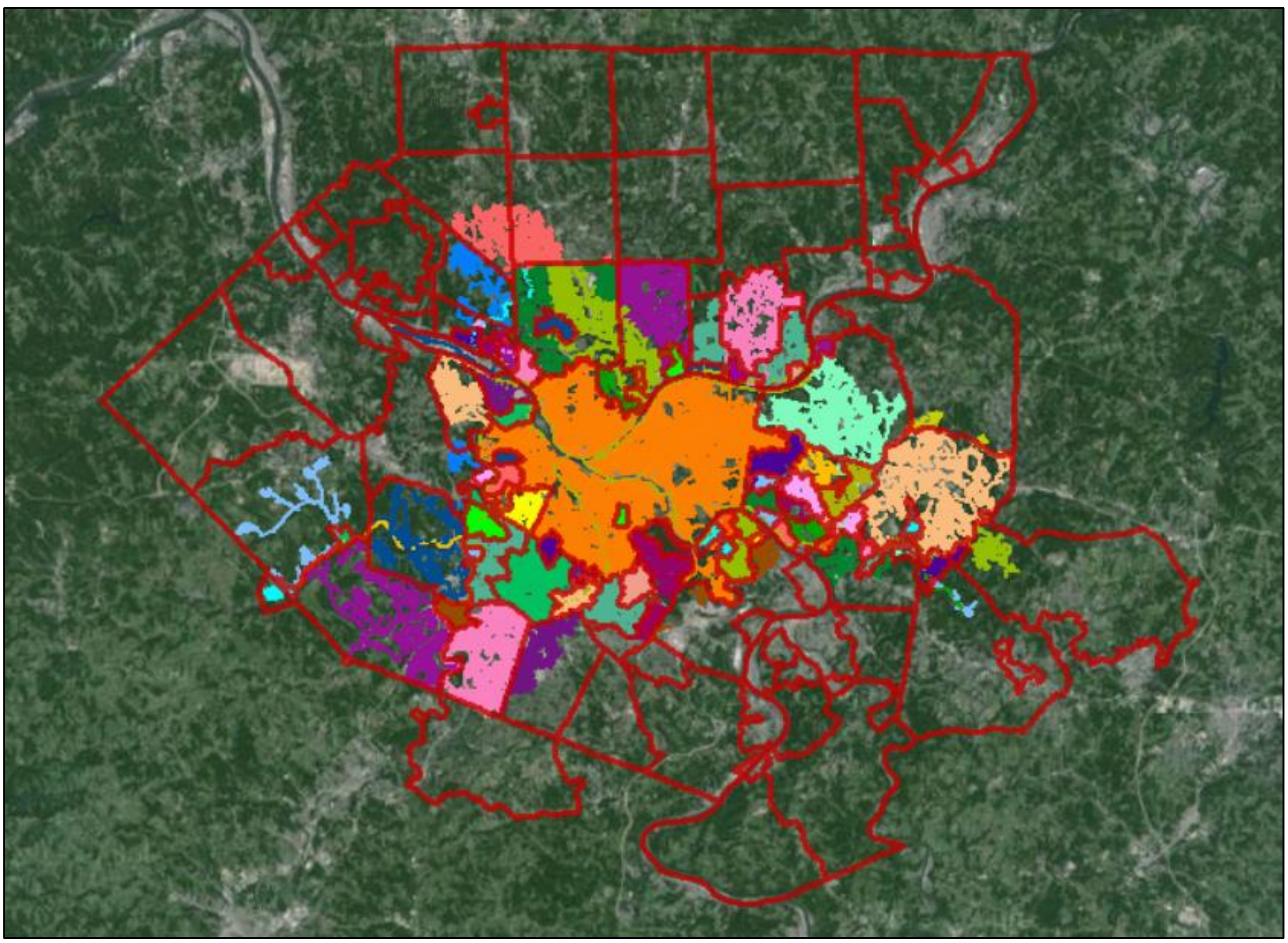

Figure 1. The ALCOSAN service area conveyance system with pipe networks color-coded by estimated ownership (e.g., the Pittsburgh Water and Sewer Authority owns and operates the pipes in the City of Pittsburgh shown in orange at the center of the map). Municipal borders are shown in dark red. (**source**: 3 Rivers Wet Weather 2013).

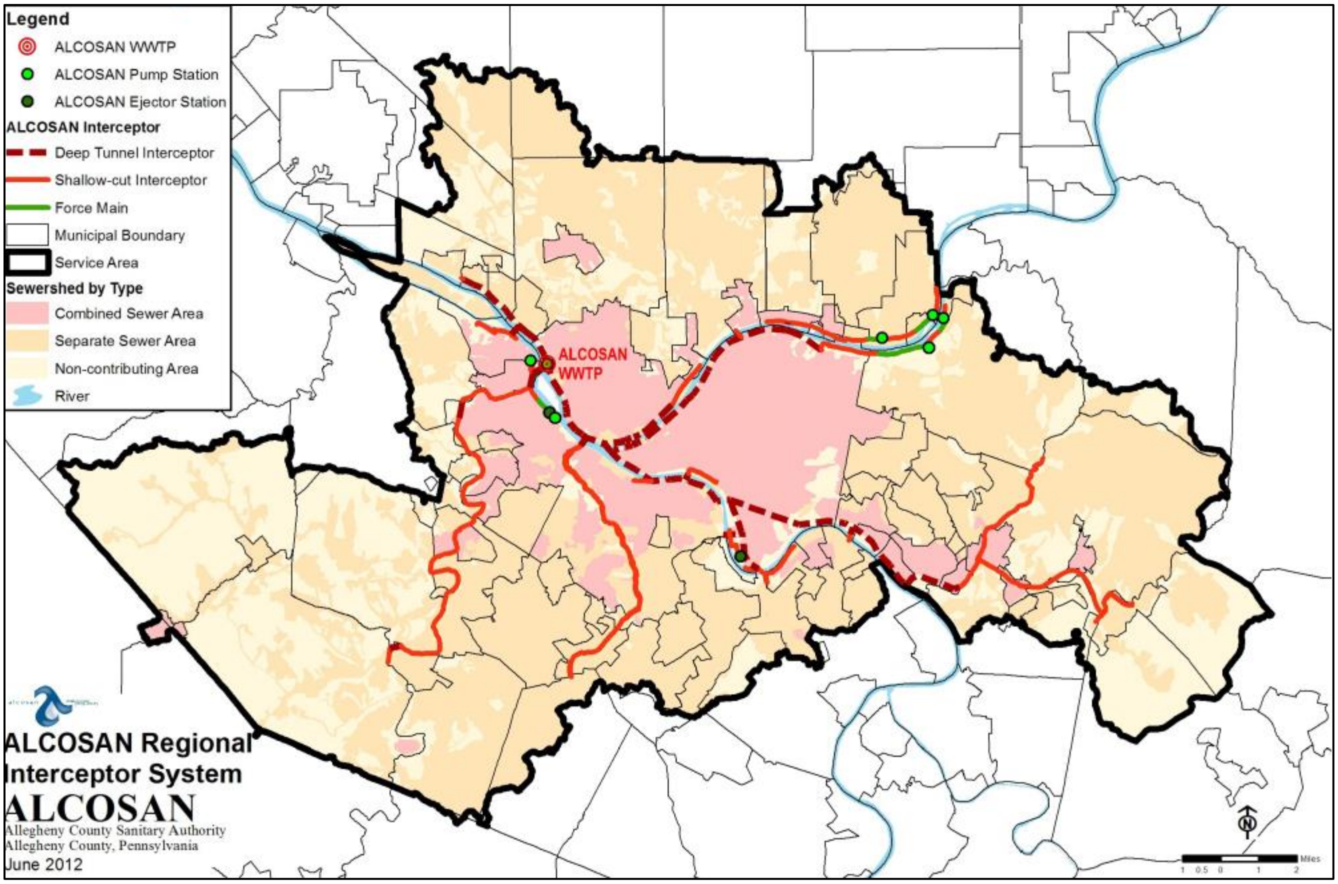

Figure 2. The ALCOSAN regional interceptor system. (**source**: ALCOSAN 2012, Figure 1-6)

OUR MODEL DESIGN

We used the AHP (Saaty 1988) and ANP (Saaty 2001) decision frameworks to evaluate four alternative arrangements of ownership and operational responsibility for various parts of the sewer system in the ALCOSAN service area:

(1) **status quo**: sewer and stormwater infrastructure ownership and operation responsibilities would remain as they are at present – with each municipality, or designated authority, responsible for the infrastructure within its borders (Figure 1) and ALCOSAN responsible for the interceptor system and Woods Run plant (Figure 2);

(2) **trunks**: large trunk sewers that serve multiple municipalities would be transferred to ALCOSAN (for more details, see Roberts and Clark 2011 and Sewer Regionalization Review Panel 2013);

(3) **basins**: new authorities would be created for seven major watersheds in the ALCOSAN service area; these new authorities would be responsible for managing sewage and stormwater infrastructure in their respective basins (for more details see ALCOSAN 2012 and Sewer Regionalization Review Panel 2013); and

(4) **regional**: essentially all sewage and stormwater infrastructure in the service area would be transferred to ALCOSAN (for more details see Sewer Regionalization Review Panel 2013).

Using SuperDecisions software, version 2.2.3, we created an AHP/ANP model to evaluate the benefits (i.e., near-term upsides), opportunities (i.e., longer-term upsides), costs (i.e., near-term downsides), and risks (i.e., longer-term downsides) of the aforementioned four alternative arrangements. We designed a three-level benefits, opportunities, costs, and risks (BOCR) model with four control criteria – legal, financial, regulatory, and organizational – nodes furcating the middle level of the decision model (Table 1). At the bottom level of the model, we considered a number of specific evaluation criteria (Table 1) nodes with respect to each of the four alternative nodes. For example, in the financial benefits branch of the model, we evaluated the potential of each alternative to achieve system investment and operation efficiencies such as consolidation of redundant billing systems (Table 1, Figure 3). Our bottom-level models were ANP models with each alternative node evaluated against each criterion node (e.g., Figure 4a), plus feedback flowing from each alternative node to each criterion node (e.g., Figure 3, Figure 4b). The weight for each evaluation criterion node (Table 1) was determined based on the pairwise judgments against each alternative node (e.g., Figure 4a) plus the feedback from the alternative nodes (e.g., Figure 4b). The bottom-level weight for each evaluation criterion node was then fed up to the model's middle level and multiplied by the respective subnet node weights; we weighted each BOCR subnet node equally at the middle level of the model, with each of the four subnet nodes receiving a weight of 0.25 (see Appendix A). Finally, at the top-level of our model we implemented four strategic criteria nodes: overflow abatement efficacy; overall cost minimization; distributional equity; and system efficiency (Figure 5). We prioritized these strategic criteria nodes using a four-tier categorization – exceptional, above average, about average, below average – of each BOCR subnet with respect to each strategic criteria (Figure 6). Based on the prioritization of our strategic criteria nodes, we weighted the benefits and costs subnets most heavily, with the risks subnet receiving the least weight (Figure 6). In summary, the "global" priority for each particular evaluation criterion node was determined by multiplying the bottom-level "local" priority with the relevant mid-level control criterion priority with the relevant top-level subnet priority as determined by the strategic criteria ratings (see Appendix A). The main goal of our model was to determine the relative rankings of each of the four alternatives with respect to the top-level strategic criteria and BOCR subnets, the mid-level control criteria, and the bottom-level evaluation criteria.

Table 1. Specific criteria evaluated for each control criteria in each subnet.

control criteria	subnet			
	benefits	opportunities	costs	risks
legal	**reduced need for complex intrasystem contracts & agreements among municipalites and ALCOSAN**	**streamlining future negotiations with regulatory bodies**	**asset transfer transaction costs** (e.g., risk assessement by ALCOSAN)	**contractual / financial obligation impediments / restrictions**
	consolidating wet weather plans into a coherent master plan	**facilitating regional water resource planning**	**costs of terminating existing & implementing new O&M agreements**	**opposition to necessary legislative revisions / amendments / approvals** (e.g., creation of ALCOSAN stormwater authority)
	expediting approval of wet weather plan(s)	**creating a coherent, hydrologic legal framework**	**costs of updating germane legislation and municipal plans** (Act 537, MAA, SWMA, MS4) **to allow for / reflect new arrangements**	**setting precedent for service centralization**
financial	**system investment & operation efficiencies** (e.g., consolidation of redundant billing systems and budgeting efforts)	**facilitating implementation of flow-based rates**	**loss of municipal cash flow**	**some municipalities may be unable to finance necessary upgrades**
	more efficient and equitable allocation of system costs (e.g., accounting for stormwater and potentially I/I)	**lower overall borrowing costs with unified system**	**costs to set up new rate systems** (e.g., to incorporate stormwater rates)	**unanticipated cost overruns**
	lower overall compliance costs by prioritizing & coordinating investments across the whole system	**encourages green infrastructure implementation** **better leverage for funding with unified system voice**	**higher overall borrowing rates with fragmented system**	**possible fines for failing to meet regulatory mandates**
regulatory	**coordinating overflow abatement strategies**	**streamlined permit applications & compliance reporting**	**inefficient flow externalization in un-integrated system**	**localized overflows in fragmented system**
	integrated stormwater and wastewater system management	**standardized system monitoring**	**suboptimal abatement coordination in fragmented system**	**continued regressive externalization of flow**
	ability to account for extra-jurisdictional flows	**unified system planning**	**regulatory bodies investing resources reviewing numerous plans**	**exacerbating decline in downstream communities**
organizational	**reduced intermunicipal regulation arbitrage**	**more balanced representation on ALCOSAN board**	**institutional redundancies and inefficiencies**	**labor / union opposition**
	compatibility with current institutional framework	**more effiicent service from centralized system authority / governance**	**creating new / reorganizing existing institutions**	**less responsive service from centralized system authority / governance**
	political palatability	**synergistic cooperation on other issues** (e.g., blight)	**crafting political consensus**	**shift away from local control**

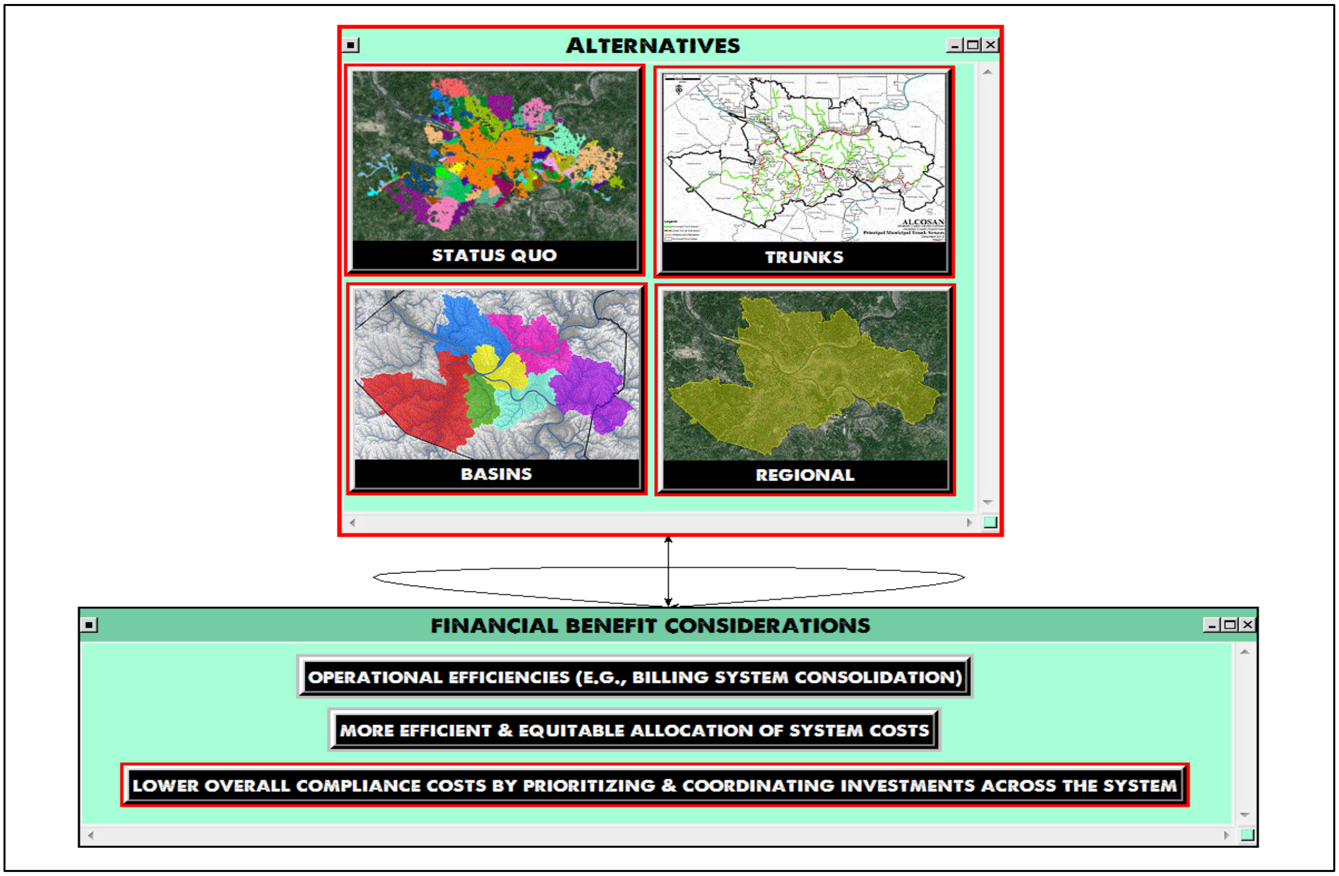

Figure 3. An example bottom-level subnet: the financial benefits subnet showing nodes connected from the operational efficiencies criterion node outlined in red.

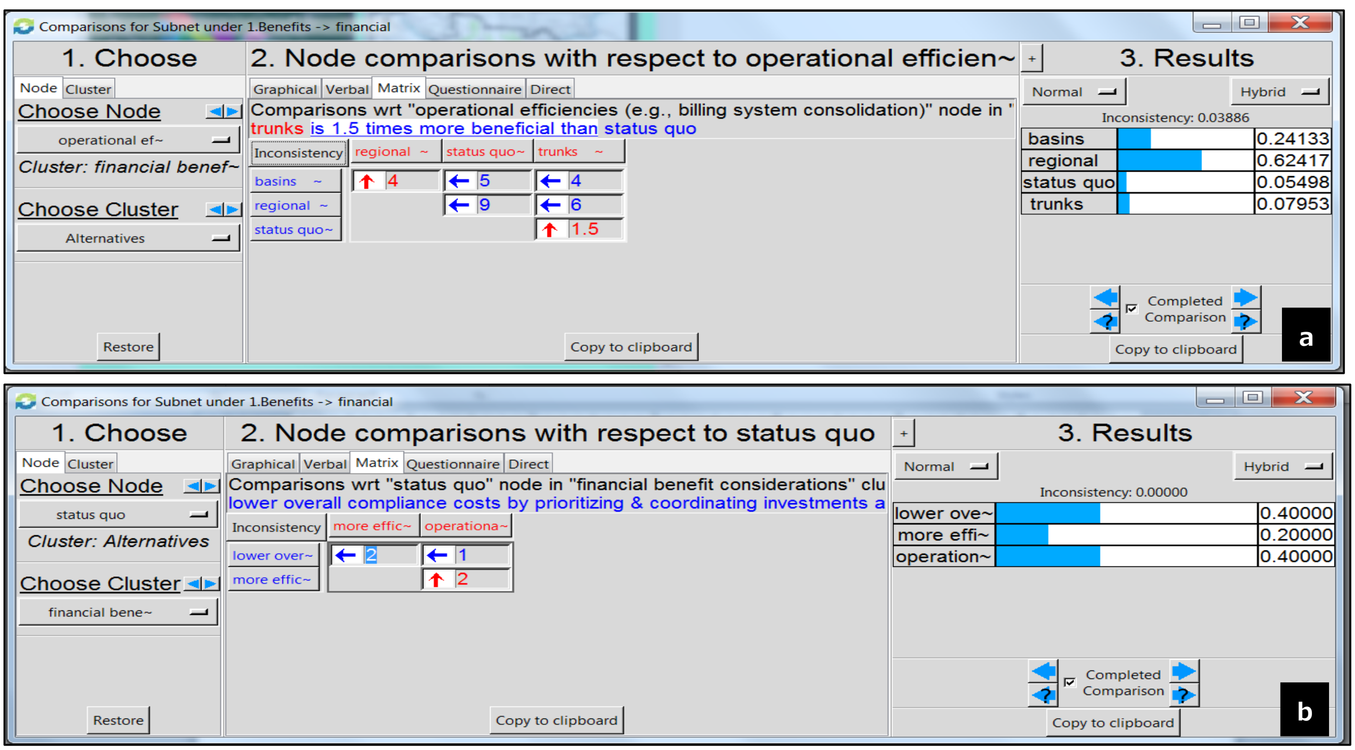

Figure 4. Example pairwise node comparisons in the financial benefits subnet: (a) alternative comparisons for the operational efficiencies node; and (b) evaluation criteria feedback comparisons for the status quo alternative.

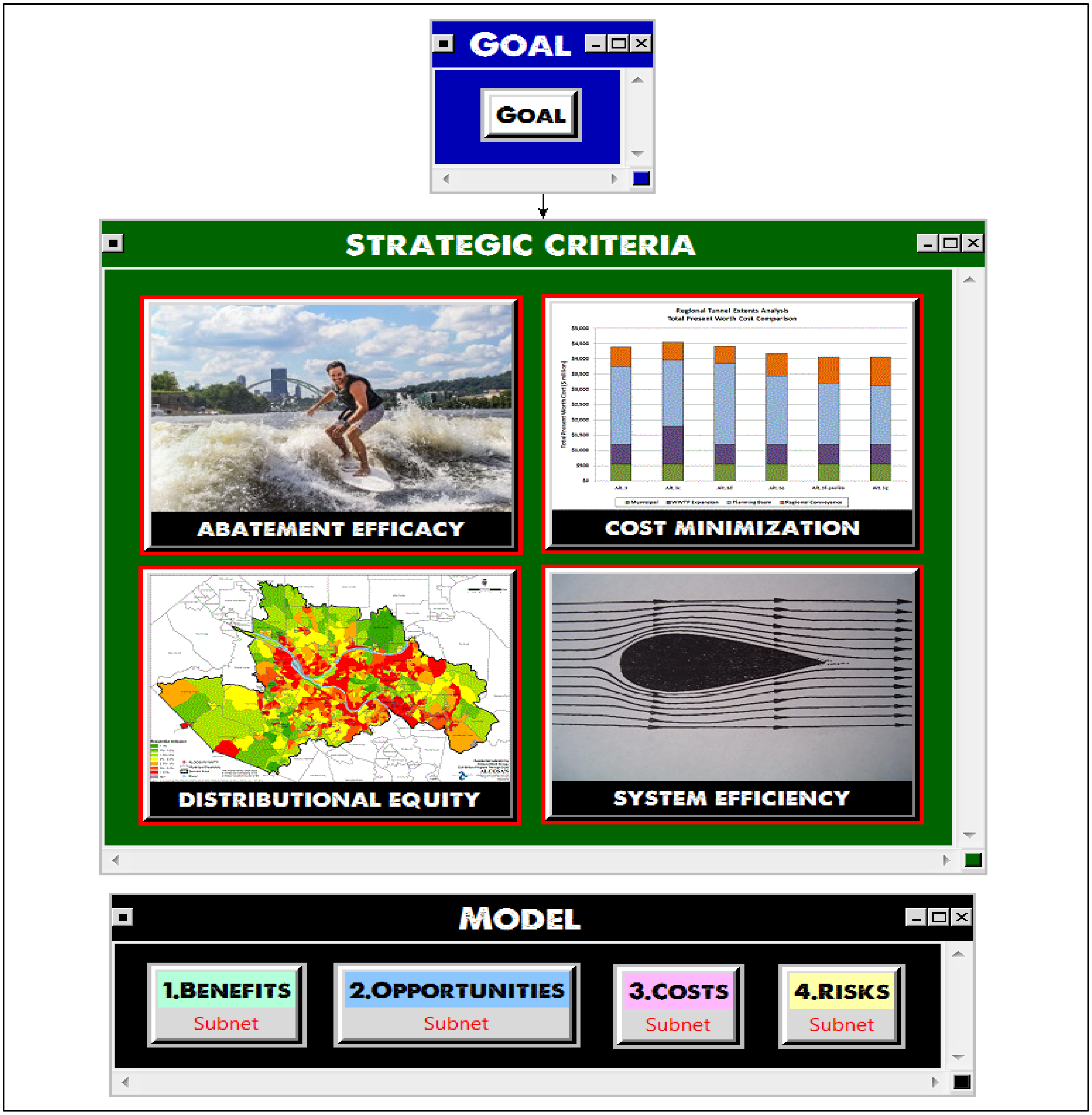

Figure 5. The top-level model with connections to the strategic criteria nodes from the main goal node outlined in red.

Super Decisions Ratings						
	Priorities	Totals	abatement efficacy 0.550510	cost minimization 0.260114	distributional equity 0.129490	system efficiency 0.059886
1.Benefits	0.383433	0.805198	1 exceptional	2 above average	2 above average	1 exceptional
2.Opportunities	0.207132	0.434971	2 above average	3 about average	2 above average	2 above average
3.Costs	0.330863	0.694802	2 above average	1 exceptional	1 exceptional	2 above average
4.Risks	0.078573	0.165000	4 below average	3 about average	4 below average	3 about average

Figure 6. The BOCR subnets – strategic criteria ratings table.

RESULTS

Synthesizing our entire model reveals that the regional alternative (i.e., all sewage and stormwater infrastructure in the service area would be transferred to ALCOSAN) is far preferable to any of the other three alternatives whether using the multiplicative synthesis formula (Figure 7a) – which indicates the marginal or short-term priorities – or the additive (negative) synthesis formula (Figure 7b) – indicating the total or long-term priorities. Both formulae also indicate the status quo alternative as least preferable. It may seem counterintuitive for the status quo to be least preferable because staying the course – in many decision scenarios – requires little in the way of investment costs. However – in the present context – the ALCOSAN service area is being mandated towards change, and – as detailed below – the regulatory implications and financial inefficiencies of maintaining the status quo confronted with this mandated change makes the status quo a decidedly unappealing option.

Drilling down into the model reveals that costs are very similar across the status quo alternative, the basins alternative, and the regional alternative, but that costs are slightly lower for the trunks alternative (Figure 8). Analyzing the middle-level of the model also shows that the risks of the trunks alternative and the basins alternative were fairly similar and appreciably less than the risks of the status quo alternative and the regional alternative (Figure 8). The differences among the four alternatives were much more pronounced for the "upside" (i.e., benefits and opportunities) subnets, with the benefits and opportunities of the regional alternative being far larger than the benefits and opportunities of any of the other three alternatives (Figure 8).

Drilling into the model further, the mid-level control criteria for each BOCR subnet show the following patterns.

> **legal**: The "upside" and "downside" (i.e., costs and risks) for each alternative largely balance out, although the magnitudes of the subnet total priorities are largest for the regional alternative, followed by the basins alternative, with the trunks and status quo alternatives exhibiting low totals for every legal subnet (Figure 9a). In other words, considering the legal criteria (Table 1), the regional alternative has large potential upside and large potential downside, while the status quo alternative offers lower risk and lower reward, but the net legal considerations approximately wash for every alternative (Figure 9a).
>
> **financial**: Considering our financial criteria (Table 1), the regional alternative displays a significant net upside while the status quo alternative exhibits a strong net downside (Figure 9b). Meanwhile, the basins alternative is an approximate wash on the financial criteria while the trunks alternative exhibits a moderate net financial downside (Figure 9a).
>
> **regulatory**: On the regulatory criteria (Table 1), the alternatives exhibit similar characteristics as the financial criteria: the regional alternative shows a large net regulatory upside; the status quo alternative shows a strong net regulatory downside; the trunks alternative shows a moderate net regulatory downside; and the basins alternative shows a moderate net regulatory upside (Figure 9c).
>
> **organizational**: Considering the organizational criteria (Table 1), each alternative approximately washes, except the basins alternative exhibits a slight net organizational downside (Figure 9d). Interestingly, the shorter-term benefits and costs comprise most of the organizational action for the status quo alternative while the regional option is more driven by longer-term organizational opportunities and risks (Figure 9d).

The evaluation criteria with the largest global priorities were in the benefits and costs subnets (Appendix A).

a

Name	Graphic	Ideals	Normals	Raw
basins		0.324829	0.225341	0.700252
regional		1.000000	0.693721	2.155758
status quo		0.031627	0.021941	0.068181
trunks		0.085046	0.058998	0.183338

b

Name	Graphic	Ideals	Normals	Raw
basins		-0.008110	-0.004380	-0.002073
regional		1.000000	0.540119	0.255612
status quo		-0.565054	-0.305196	-0.144434
trunks		-0.278280	-0.150304	-0.071132

Figure 7. Overall synthesized (a) multiplicative and (b) additive (negative) priorities for each alternative.

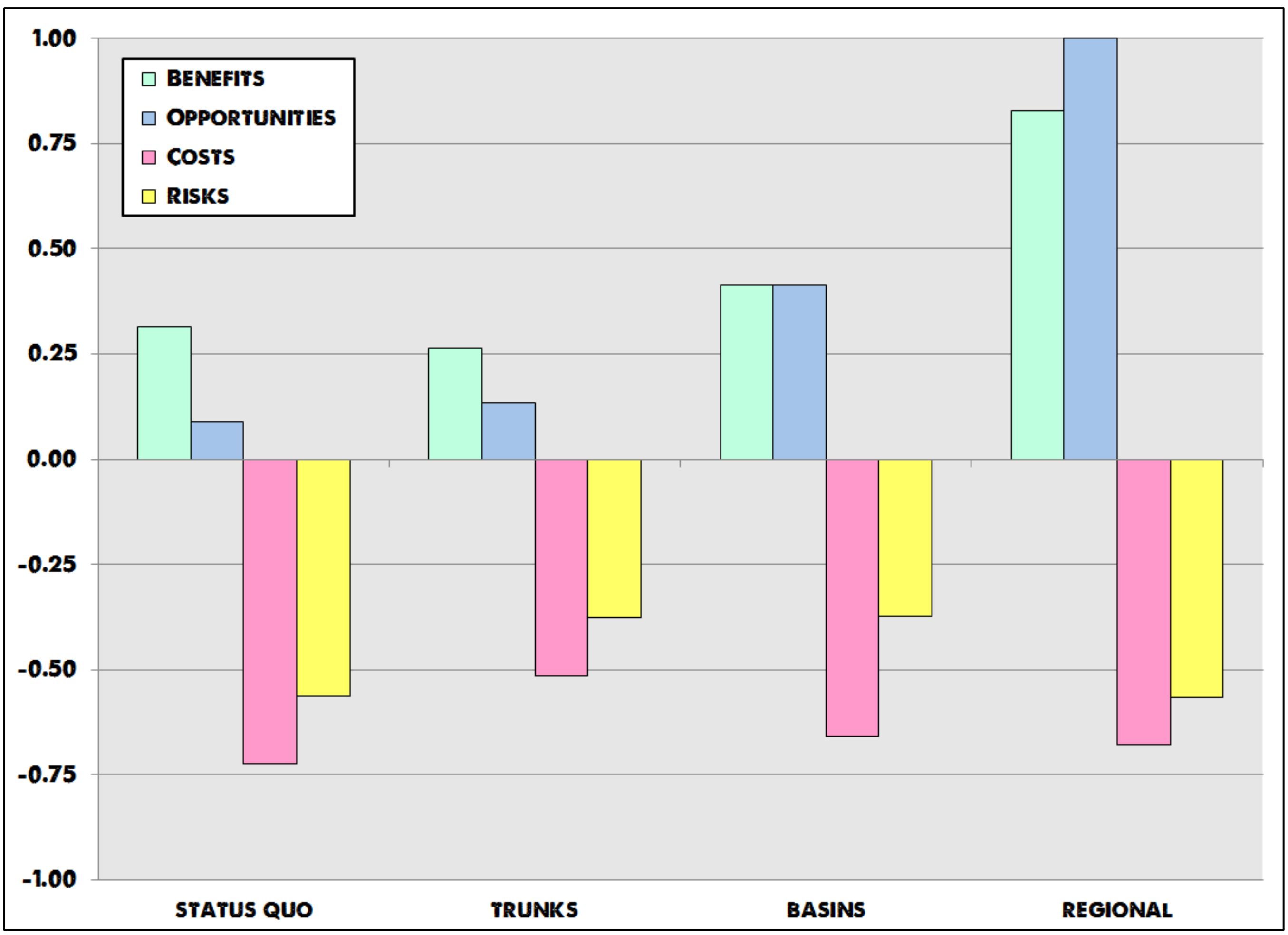

Figure 8. Total BOCR subnet priorities for each alternative.

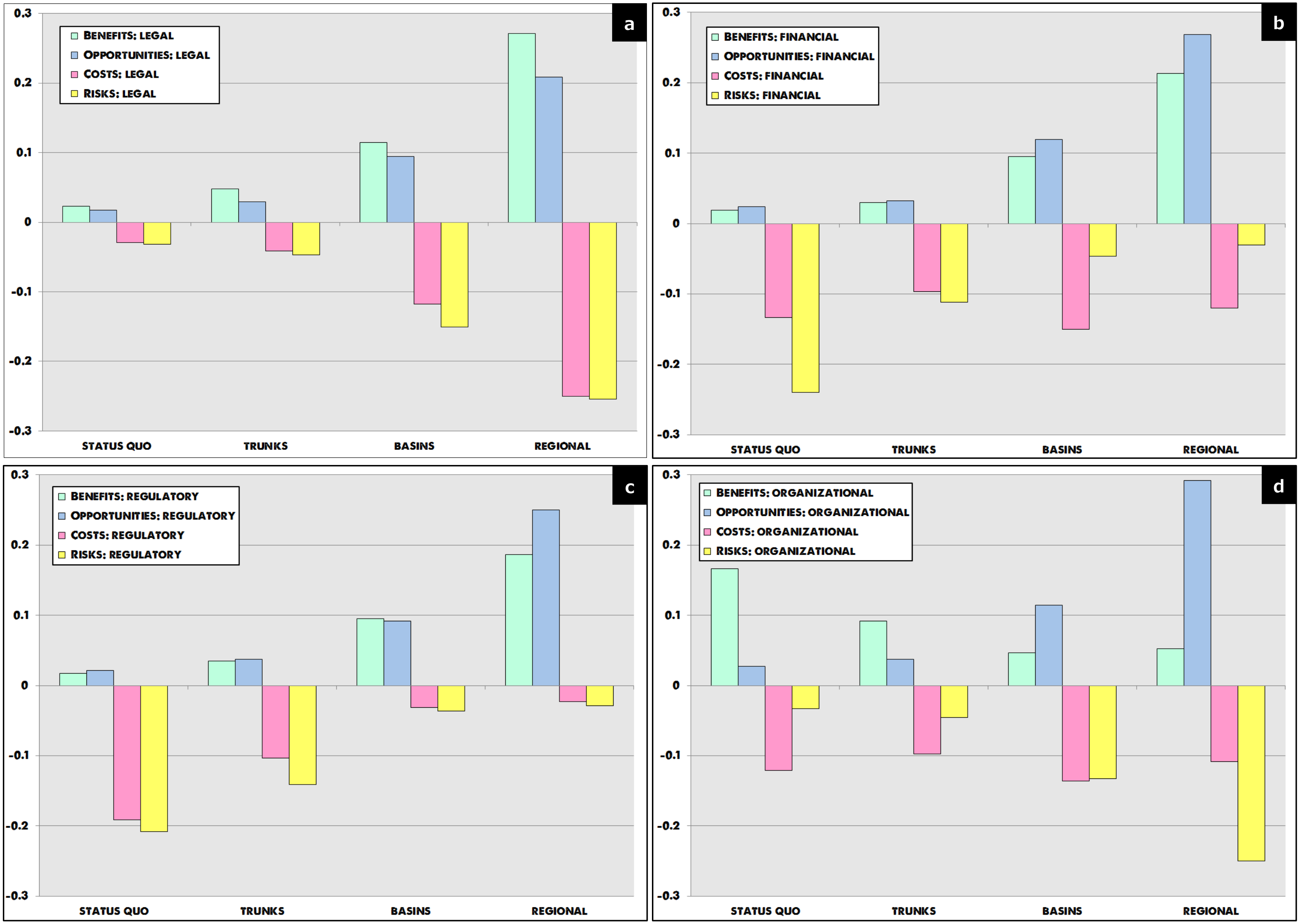

Figure 9. Total BOCR subnet priorities for each alternative by control criteria: (a) legal; (b) financial; (c) regulatory; and (d) organizational.

SENSITIVITY ANALYSIS

The sensitivity function of SuperDecisions shows that dominant preferability of the regional alternative is robust to any range of prioritization of the benefits (Figure 10a) and opportunities (Figure 10b) subnets. However, the SuperDecisions sensitivity function shows that – considering just the costs subnet – the trunks alternative becomes preferable – although net negatively – when costs are prioritized at roughly 60% or above (Figure 10c). Likewise, the basins alternative becomes most – but net-negative – preferable in terms of risks when the risks subnet is prioritized at about 44% or higher, with the trunks alternative running a close second (Figure 10d). However, the large upside performance edge of the regional alternative compared with the relatively slight performance edge of other alternatives when costs and/or risks are highly prioritized indicates that the regional alternative is the net preferable alternative regardless of how much priority is given to each BOCR subnet.

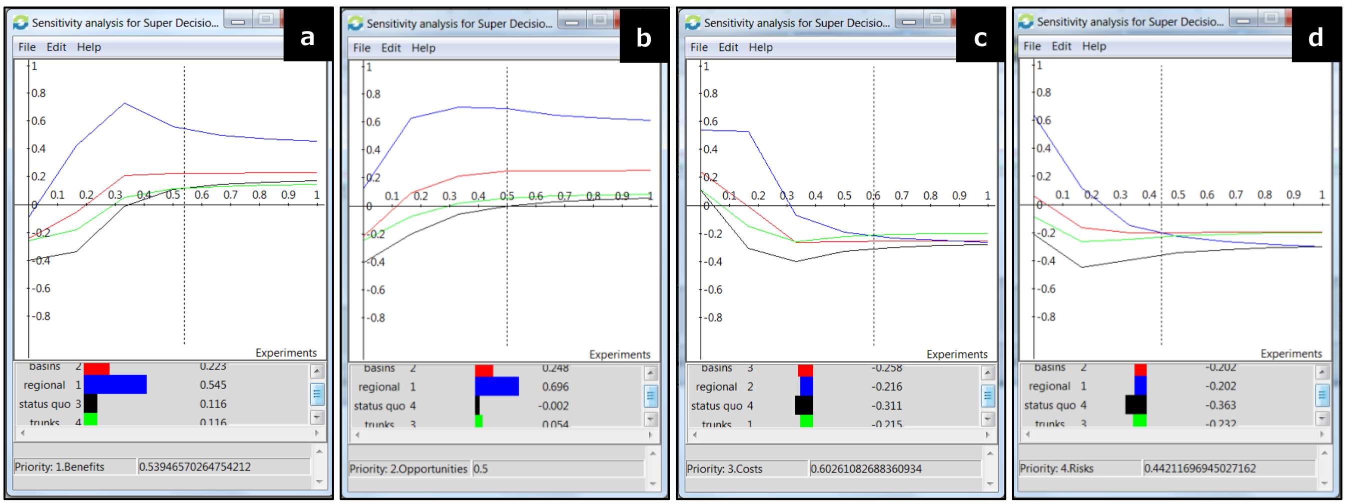

Figure 10. Alternative priority sensitivity curves for: (a) benefits; (b) opportunities; (c) costs; and (d) risks.

DISCUSSION

Our model strongly and consistently suggests the regional alternative is the most favorable of the four alternatives evaluated. The main criteria driving the preferability of the regional alternative in our specification were the strong financial and regulatory benefits and opportunities offered by a unified regional system. On the flipside, our model indicates the least preferable alternative is the status quo alternative, mainly because of the strong financial and regulatory costs and risks associated with a highly fragmented system. Our results add further evidence to the long-standing call for regionalization of the sewer and stormwater infrastructure in the ALCOSAN service area (e.g., Environmental Law Institute 1999, Sewer Regionalization Review Panel 2013).

Although we believe our model tenably captures and represents the most pertinent considerations of infrastructure ownership and operational regionalization in the ALCOSAN service area, by no means do we consider our model the definitive representation of collective consensus on the issue. Our model results reflect our choices of particular criteria as well as the relationships among and prioritizations of those criteria. However, the salient strength of our AHP/ANP approach, implemented with SuperDecisions software, is that our decision process (i.e., model) is fully documented, quantified, and examinable. Although individuals or organizations may disagree with our particular model specification, the appeal and efficacy of our AHP/ANP model is that it can be modified to account for different perspectives, changing conditions, and new information.

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APPENDIX A: local & global priorities (highest global priorities highlighted – descending – in red, orange, and yellow)

subnet	subnet priority	control criteria	control criteria priorities	evaluation criteria	local priority	global priority
Benefits	0.383	**legal**	0.25	reduced need for complex contracts & agreements	0.342	0.033
				consolidating wet weather plans	0.320	0.031
				expediting approval of wet weather plan(s)	0.338	0.032
		financial	0.25	operational efficiencies	0.444	0.043
				lower overall compliance costs...	0.444	0.043
				more efficient & equitable allocation...	0.111	0.011
		regulatory	0.25	coordinating overflow abatement strategies	0.186	0.018
				integrated stormwater-wastewater management	0.385	0.037
				ability of account for extra-jurisdictional flows	0.429	0.041
		organizational	0.25	compatibility with current institutional framework	0.444	0.043
				reduce intermunicipal regulation arbitrage	0.111	0.011
				political palatability	0.444	0.043
Opportunities	0.207	**legal**	0.25	streamlining negotiations with regulatory bodies	0.077	0.004
				facilitating regional water resource planning	0.513	0.027
				creating a coherent, hydrologic legal framework	0.410	0.021
		financial	0.25	encouraging green infrastructure implementation	0.300	0.016
				facilitating implementation of flow-based rates	0.200	0.010
				lower overall borrowing costs with unified system	0.200	0.010
				better leverage for funding with unified system	0.300	0.016
		regulatory	0.25	streamlined permit applications & compliance...	0.341	0.018
				standardized system monitoring	0.366	0.019
				unified system planning	0.293	0.015
		organizational	0.25	more balanced representation on ALCOSAN board	0.222	0.012
				more efficient service from centralized system...	0.444	0.023
				synergistic cooperation on other issues	0.333	0.017
Costs	0.331	**legal**	0.25	asset transfer transactions	0.468	0.039
				terminating existing & implementing new O&M agreements	0.095	0.008
				updating legislation	0.437	0.036
		financial	0.25	costs to set up new rate systems	0.200	0.017
				higher overall borrowing rates in fragmented system	0.400	0.033
				loss of municipal cash flow	0.400	0.033
		regulatory	0.25	inefficient flow externalization...	0.432	0.036
				regulatory bodies investing resources...	0.074	0.006
				suboptimal abatement coordination...	0.494	0.041
		organizational	0.25	crafting political consensus	0.273	0.023
				creating new / reorganizing existing institutions	0.318	0.026
				institutional redundancies & inefficiencies	0.409	0.034
Risks	0.079	**legal**	0.25	contractual obligation impediments	0.267	0.005
				opposition to necessary legislative revisions	0.600	0.012
				setting precedent for service centralization	0.133	0.003
		financial	0.25	possible fines for failing to meet regulatory...	0.226	0.004
				some municipalities may be unable to finance necessary...	0.499	0.010
				unanticipated cost overruns	0.274	0.005
		regulatory	0.25	continued regressive flow externalization	0.235	0.005
				exacerbating decline in downstream communities	0.412	0.008
				localized overflows in fragmented system	0.353	0.007
		organizational	0.25	labor / union opposition	0.429	0.008
				less responsive service from centralized authority	0.286	0.006
				shift away from local control	0.286	0.006