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Application of the water needs index: Can Tho City, Mekong Delta, Vietnam

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Abstract

Provision of urban water supplies to rapidly growing cities of South East Asia is difficult because of increasing demand for limited water supplies, periodic droughts, and depletion and contamination of surface and groundwater. In such adverse environments, effective policy and planning processes are required to secure adequate water supplies. Developing a Water Needs Index reveals key elements of the complex urban water supply by means of a participatory approach for rapid and interdisciplinary assessment. The index uses deliberative interactions with stakeholders to create opportunities for mutual understanding, confirmation of constructs and capacity building of all involved. In Can Tho City, located at the heart of the Mekong delta in Vietnam, a Water Needs Index has been developed with local stakeholders. The functional attributes of the Water Needs Index at this urban scale have been critically appraised. Systemic water issues, supply problems, health issues and inadequate, poorly functioning infrastructure requiring attention from local authorities have been identified. Entrenched social and economic inequities in access to water and sanitation, as well as polluting environmental management practices has caused widespread problems for urban populations. The framework provides a common language based on systems thinking, increased cross-sectoral communication, as well as increased recognition of problem issues; this ought to lead to improved urban water management. Importantly, the case study shows that the approach can help to overcome biases of local planners based on their limited experience (information black spots), to allow them to address problems experienced in all areas of the city.

Keywords

index, city, needs, delta, water, can, vietnam, tho, application, mekong

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Application of the Water Needs Index: Can Tho City, Mekong Delta, Vietnam

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9 Vietnam.

10 **Abstract**

11 Provision of urban water supplies to rapidly growing cities of South East Asia is difficult
12 because of increasing demand for limited water supplies, periodic droughts, and depletion and
13 contamination of surface and groundwater. In such adverse environments, effective policy and
14 planning processes are required to secure adequate water supplies. Developing a Water Needs
15 Index reveals key elements of the complex urban water supply by means of a participatory
16 approach for rapid and interdisciplinary assessment. The index uses deliberative interactions
17 with stakeholders to create opportunities for mutual understanding, confirmation of constructs
18 and capacity building of all involved. In Can Tho City, located at the heart of the Mekong delta
19 in Vietnam, a Water Needs Index has been developed with local stakeholders. The functional
20 attributes of the Water Needs Index at this urban scale have been critically appraised. Systemic
21 water issues, supply problems, health issues and inadequate, poorly functioning infrastructure
22 requiring attention from local authorities have been identified. Entrenched social and economic
23 inequities in access to water and sanitation, as well as polluting environmental management
24 practices has caused widespread problems for urban populations. The framework provides a
25 common language based on systems thinking, increased cross-sectoral communication, as well

26 as increased recognition of problem issues; this ought to lead to improved urban water
27 management. Importantly, the case study shows that the approach can help to overcome biases
28 of local planners based on their limited experience (information black spots), to allow them to
29 address problems experienced in all areas of the city.

30 **Key words:** index; participatory assessment; urban water; water supply; Vietnam

31 **1. Introduction**

32 Many countries face challenges posed by increasing demand for limited water supplies, periodic
33 droughts, and depletion and contamination of surface and groundwater (Moglia et al., 2008b;
34 Timmer et al., 2007; UNDP, 2006; Vörösmarty et al., 2000; Wakidaa and Lerner, 2004). Many
35 locations are experiencing severe water shortages and difficulties (Abu Zahra, 2001; Henriques,
36 2011) and urban areas are a critical component of the world's water crisis (Grohmann, 2009).
37 This has implications for policy and planning processes required to secure adequate water
38 supplies into the future (UNDP, 2006).

39 Concerted efforts to obtain accurate and comprehensive data on water resources are essential for
40 planning purposes. Reliable and accurate information on the status and demand for water supply
41 and sanitation services is typically unavailable, outdated or of questionable validity (Alexander
42 et al., 2010; Molle and Mollinga, 2003). Difficulties arise in ascertaining the most important
43 factors to consider in the management of water resources (Alexander et al., 2010; Barnett et al.,
44 2008). Adopting a systems perspective can assist water planners responsible for infrastructure
45 and supply management, yet analysis for the purposes of water planning can be an onerous and
46 complex task (Moglia et al., 2012). Increasingly, participatory assessment is considered an
47 approach that is useful in combining stakeholder engagement and knowledge elicitation
48 (Barreteau, 2003; Daniell et al., 2010; Dray et al., 2006; Ribarova et al., 2011). Such modelling
49 techniques can support collective decision-making in areas of natural resource management
50 (Jones et al., 2009). A useful participatory assessment approach is the Water Needs Index
51 (WNI), which minimises modelling activities while maximising integration of local knowledge

52 (Alexander et al., 2011). The WNI has been based on the Climate Vulnerability Index
53 developed by Sullivan and Meigh (2005) and extended by provision of involvement of local
54 stakeholders in development and understanding of the index. The WNI is an interdisciplinary
55 approach that can be used to identify systemic water issues and hotspots that require attention
56 from local water authorities (Alexander et al., 2010; Alexander et al., 2011). The process
57 involves a systems analysis using a weighted multi-criteria assessment within a hierarchy of
58 dimensions and data sources. The key task is the definition of dimensions, and then the selection
59 of data sources to be used to populate the dimensions. The selected data sources are either
60 observations or proxies of the dimensions. While mathematical computations are
61 straightforward, constructing the index and accessing suitable data is difficult and complex,
62 with considerable subjective judgment required in the choice of dimensions. Reliability and
63 accuracy of the data sources is also important to the process but the reliability and
64 representativeness of chosen data sources may be often difficult to assess as data acquisition is
65 often questionable. Alexander et al. (2010) discusses the inherent difficulties of inference that
66 occur when using proxies. This can be in reference to problems of variable data quality,
67 geographic scale, and differences in collection methods making the choice of indicators a matter
68 of judgment.

69 There are often tendencies to overly simplify and provide deterministic explanations of the
70 complex dynamics of the water cycle, and impacts on collection, use and storage. To alleviate as
71 many concerns as possible and enhance legitimacy of assessments, the WNI methodology is
72 embedded in a mixed methodological framework incorporating post-normal, adaptive
73 methodologies that combine quantitative with qualitative methods of research, as per
74 recommendations by Creswell (2009). The approach of developing an index based on a
75 deliberative methodology had already been successfully tested in previous studies by the
76 authors (Alexander et al., 2011; Moglia et al., 2009).

77 The WNI index typically incorporates a number of factors, using a deliberative process with
78 stakeholders to determine the water needs of a range of locations and populations (Alexander et

79 al., 2009a; Alexander et al., 2009b; Alexander et al., 2010; Alexander et al., 2011; Moglia et al.,
80 2008a; Moglia et al., 2010a). This process is a post-normal scientific approach that is useful
81 when all factors are not necessarily knowable and where accessing all relevant information is
82 too time consuming or unclear and affected by high levels of uncertainty (Funtowicz and
83 Ravetz, 1993). The WNI methodology has been used to inform development of preliminary
84 information embedded in Integrated Urban Water Management approaches which take a more
85 holistic systems' perspective when planning for urban water management, as used in research
86 by Maheepala et al. (2010). These approaches provide a means to manage water resources more
87 sustainably by accounting for natural flows, water quality, water extraction, and balancing
88 environmental and community needs.

89 This paper describes a study, *Climate Adaptation through Sustainable Urban Development*. The
90 application of the WNI framework, described in this paper, has been a critical step in activity to
91 understand the current situation of Can Tho City and to obtain data, aiming at setting up a good
92 foundation for better urban water management in the study site. The WNI framework has helped
93 provide a foundation for subsequent research by: 1) identifying the location specific urban water
94 needs; 2) providing a frame of reference and a common language for the study; and 3) engaging
95 stakeholders around a collective assessment of the problems which helps to legitimise study
96 outcomes.

97 The paper is organised with descriptions of the: 1) case study context; 2) methodology including
98 an initial workshop, a sector review and collation and analysis of selected data; 3) results and
99 data; and finally 4) discussion and conclusions. The paper also describes some of the benefits of
100 the WNI approach in terms of the study, as well as the benefits to local planners and decision
101 makers.

102 **2. Case study description**

103 Can Tho City is a fast growing city in the Mekong Delta of Vietnam. According to the local
104 government urban planners the anticipated growth of residential, commercial, and industrial

105 areas will be continuous, outstripping infrastructure that is already incapable of supplying the
106 city needs (SIURP, 2010). In 2008, the city housed about 1.2 million inhabitants, and by 2020
107 the population is expected to increase to approximately 1.65 million (SIURP, 2010). In Can Tho
108 City, there is an on-going migration of people from rural to urban areas , as is occurring all over
109 the globe, and the percentage of urban population is expected to increase from 59 % in 2008 to
110 70 % in 2020 (SIURP, 2010). Rapid population growth and economic development has placed
111 enormous pressure on the surrounding natural and built environments. In addition, investments
112 in water-related infrastructure for supply and sanitation have not kept pace with urban growth,
113 particularly in areas of rural-urban interface (Herbst et al., 2009). Likewise, there are growing
114 concerns regarding a rapid degradation of river water quality, due primarily to the discharge of
115 untreated wastewater from households, agriculture and industry (Herbst et al., 2009). The WNI
116 describes the issues of infrastructure and access to services, groundwater systems, flooding
117 concerns, and aquatic ecosystems, and these matters are described and discussed.

118 **2.1 Infrastructure and access to services**

119 Water and sanitation service in Can Tho City are provided by the Water Supply and Sanitation
120 Company (WSSC) in the main established urban settlements, with limited coverage in the peri-
121 urban and rural areas (Neumann et al., 2011). The Centre of Clean Water and Environmental
122 Sanitation (CCWES) of the Department of Agriculture and Rural Development (DARD) are
123 responsible for servicing the peri-urban and rural areas, using community scale groundwater
124 schemes. The largest pipe network services the Ninh Kieu district (see Figure 1), which is the
125 most urbanised district of the city. The pipe network is also significant in urban areas along the
126 Hau River from Binh Thuy to O Mon (see Figure 1). Smaller water supply networks service
127 urban areas in the O Mon and Thot Not districts (see Figure 1), which are more distant to the
128 main urban area. New urban development areas in South Can Tho (Cai Rang district, see Figure
129 1) are serviced by new water supply networks provided by developers. The water extracted from
130 the rivers is treated at water treatment plants (WTPs) before distribution to households and
131 businesses. There are currently eleven WTPs, seven of which are serving the five urban

132 districts. The other four are serving the small towns of the rural districts. The total capacity of
133 the WTPs for the whole city is 129 ML/day.

134 **2.2 Groundwater systems**

135 Groundwater is a valuable resource for the community in Can Tho City and groundwater in the
136 Mekong Delta has been extracted for freshwater demand for over a century (Hung et al., 1998).
137 Household shallow tube-wells typically extract groundwater from a depth of 80–120 metres.
138 Groundwater wells for groundwater supply units and industrial uses access groundwater at a
139 depth of 100 to 250 metres (Thanh, 2008). A survey found that 60% of wells access the
140 Pleistocene aquifer (IUCN, 2011). Water quality analysis of monitored Can Tho wells
141 demonstrated elevated levels of total coliforms (Department of Natural Resources and
142 Environment, 2009). This could be indicative of pollution from inadequate sanitation systems
143 and infiltration of polluted urban runoff entering groundwater wells (Neumann et al., 2011). The
144 main trends threatening the sustainability of groundwater resources in Can Tho are declining
145 groundwater levels and declining groundwater quality. Over-exploitation of water sources,
146 saltwater intrusion and pollution are considered the reasons for the decline in groundwater
147 storage and quality by Neumann et al. (2011).

148 **2.3 Flooding issues**

149 The Mekong Delta has an annual water cycle impacted by upstream flows from the basin and
150 seasonal fluctuations in river flows from monsoonal precipitation events. Floods in the Mekong
151 are considered beneficial, with annual flooding relinquishing nutrients and sediment to the
152 floodplains. Large floods in the Mekong Delta, however, can typically lead to significant
153 damage to houses, crops and infrastructure and may be hazardous to inhabitants (Tuan et al.,
154 2007). The monsoonal rainy season in Can Tho occurs between May to November, releasing
155 approximately 90% of the annual rainfall. During the rainy season, increased upstream flows,
156 tidal surges and intense rainfall sometimes combine to cause widespread flooding across Can

157 Tho City (Tuan et al., 2007). In addition, sea level rise and salt water intrusion is likely to be of
158 significant concern (current and/or future) for Can Tho City (Dragon Institute, 2009).

159 **2.4 Aquatic eco-systems**

160 The Mekong basin is one of the richest areas of biodiversity in the world (Gephart et al., 2010).
161 The Mekong Delta ecosystem is critical for the region, providing sustenance through fisheries
162 and the support of aqua-culture (Gephart et al., 2010). A number of aquatic species in the lower
163 Mekong are listed as endangered or critically endangered (Dudgeon, 2000). Neumann et al
164 (2011) has recognised that urban pollution, upstream development in the Mekong, overfishing,
165 agriculture and aquaculture continue to place key pressures on ecosystems in the delta.

166 **3. Methodology and data**

167 The WNI methodology has been developed, justified and described in previous papers and
168 reports (Moglia et al., 2008a; Alexander et al., 2009a; Alexander et al., 2009b; Alexander et al.
169 2010; Alexander et al. 2012). A workshop involving key stakeholders was held in October 2010
170 where the WNI framework (Alexander et al., 2010; Sullivan, 2002; Sullivan and Meigh, 2005),
171 was adapted to the local context (Moglia et al., 2010a). In addition, an engagement process
172 involving additional local stakeholders provided local knowledge to inform the development of
173 the WNI. These processes informed a sector review, and identified available data sources
174 (Neumann et al., 2011). A householder survey was undertaken to address information gaps in
175 data (Neumann et al., 2012). The selection of indicators for the WNI occurred through a
176 subjective process involving the national and international research teams and local
177 stakeholders, in an iterative process over several months.

178 **3.1 Index methodology**

179 The WNI was developed within an index framework, drawing on the Climate Vulnerability
180 Index (Sullivan and Meigh, 2005), which is an extension of the Water Poverty Index (Sullivan,
181 2002). The aim of the framework was to determine the water needs of a range of locations by
182 incorporating the biophysical, economic and social drivers linking water, environment and

183 poverty. The approach involved selection of indices used to identify systemic water issues and
184 identification of hotspots that require attention. The more constructive term ‘Needs’ was chosen
185 rather than the potentially pejorative term ‘Poverty’. Initial applications of the WNI were at
186 regional and national scales to inform funding priorities for investments in water aid (Moglia et
187 al., 2008a). In response to case study learnings it was recognised that the WNI was useful when
188 co-constructed with water managers at the catchment scale (Alexander et al., 2009a; Alexander
189 et al., 2009b; Alexander et al., 2010). The first study application involving the WNI had six
190 dimensions, i.e. Resources (R), Capacity (C), Use (U), Access (A), Environment (E) and
191 Vulnerability (V) (Alexander et al., 2010). The generic calculation of the index is based on its
192 dimensions using a weighted average:

$$193 \quad WNI = (R \cdot w_R) + (C \cdot w_C) + (U \cdot w_U) + (E \cdot w_E) + (A \cdot w_A) + (V \cdot w_V) \quad (1)$$

194 Each of the dimension values are between 0 and 100, and the weights w_k are all between 0 and 1
195 and add up to 1 as per Equation (2).

$$196 \quad w_R + w_C + w_U + w_E + w_A + w_V = 1 \quad (2)$$

197 For the WNI, dimensions are changeable and are adjusted on the basis of the deliberation
198 process outcomes.

199 **3.2 Workshop deliberation process**

200 The WNI workshop was designed to not only identify WNI dimensions and potential indicators,
201 but also to facilitate a broader discussion of the issues related to water within the region.
202 Specifically, the aims were to:

- 203 • Introduce the project and water risk concepts to stakeholders through interactive and
204 practical activities.
- 205 • Confirm the geographical scope of the project, i.e. five urban districts of Can Tho City.
- 206 • Provide opportunity for local stakeholders to shape the project’s focus.

- 207 • Facilitate discussions on Can Tho City water and sanitation from a systems perspective.
- 208 • Generate a deeper understanding of the Can Tho City water and sanitation system and
- 209 water needs, based on six dimensions of the WNI.
- 210 • Identify sources and acquisition of data relating to the six dimensions.

211 Key stakeholders were identified and invited to the workshop, on the basis of a stakeholder

212 mapping exercise during previous scoping study trips, confirmed by Can Tho University¹ and

213 Institute of Sustainable Futures² researchers involved in projects in the region. The stakeholder

214 mapping exercise is described in the workshop report (Moglia et al., 2010a). Key participants

215 included local staff from the WSSC, Department of Natural Resource and Environment

216 (DONRE), Department of Planning & Investment (DPI), Department of Labor, Invalids &

217 Social Affairs (DoLISA), City Institute for Socio-Economic Development Studies (CIDS),

218 Department of Construction (DOC), and the Department of Agriculture and Rural Development

219 (DARD). This is a sub-set (8 out of 12) of the stakeholder organisations that were identified in

220 the stakeholder mapping exercise. Whilst all key stakeholders were invited, only some decided

221 to participate.

222 The workshop deliberation process occurred through the sequence of: 1) introduction of project,

223 2) description and discussion of the methodology, 3) definition of the six dimensions and their

224 associated issues in the Can Tho City context, 4) exploration of the dimensions from a

225 geographical perspective, and 5) discussion of the impacts of climate change and/or urban

226 development on dimensions, and finally 6) discussion of and weighting (ranking) of the relative

227 importance of the dimensions. This process identified the important issues within the

228 dimensions, as well as available data sources. It was however found that many of the identified

229 data sources were not in a spatial format, and hence unsuitable for the WNI, as used by

230 Alexander et al (2010). For the case study context (i.e. the more urbanised areas of Can Tho

231 City) it was perceived that the urban situation and the focus on climate change adaptation and

¹ For more details, see <http://websrv.ctu.edu.vn/en/>

² For more details, see <http://www.isf.uts.edu.au/>

232 urban development warranted a different set of dimensions identified by the research team. The
233 workshop assisted in determination of the dimensions and in discussions of the associated issues
234 Final dimensions are listed:

- 235 • Water and sanitation access (W): relating to households and other customers access
236 style to water and sanitation services.
- 237 • Quality of accessed water (Q): relating fit for purpose water supply quality, measured
238 using health impacts
- 239 • Aquatic ecosystems (A): relating to the health of river and other freshwater eco-systems
240 and surface water quality
- 241 • Flooding (F): relates to damages from floods, effectiveness of protection measures, and
242 frequency of flood occurrences.
- 243 • Infrastructure performance (I): relates to issues such as leakage, inadequate pressure,
244 adequacy and condition of storages, and occurrences of infrastructure breakages.
- 245 • Groundwater issues (G): relates to over-extraction of groundwater, pollution of
246 groundwater, protection measures and salinity intrusion.

247 **3.3 Selection of indicators**

248 The workshop helped in identifying a range of data sources that could potentially be used to
249 quantify the WNI. Nine indicators were selected and used to quantify the six dimensions. The
250 indicators comprised social, economic, and biophysical measures as summarised in Table 1.
251 Data for each indicator was collected by the national research team based in Can Tho after
252 identifying the data location and local departments and institutes responsible. The data was
253 reviewed and synthesised into a coherent urban water sector review (Neumann et al., 2011). The
254 WNI dimensions were used to structure the review, and provided a qualitative analysis of the
255 situation in Can Tho. It was identified in the workshop and the subsequent review that there
256 were gaps in the information available in terms of understanding the various aspects of the

257 urban water systems. In order to explore some of the issues not covered by existing data, a
258 survey of 1,200 households was undertaken (Neumann et al., 2012). This survey covered a
259 number of wards (i.e. an administrative area in Can Tho, within a district), chosen to adequately
260 represent the range of relevant situations in Can Tho City, and to cover a number of critical
261 topics, such as; 1) impacts of flooding, 2) perceptions of water qualities, 3) quality and source of
262 water that households use for different purposes, and 4) sanitation coverage, for which there
263 existed only patchy or no information. The data from the household survey was extremely
264 useful in quantification of the WNI and verification of key water supply issues.

265 In summary, the output of the WNI workshop, the data review, and the household survey
266 (Moglia et al., 2010a; Neumann et al., 2012; Neumann et al., 2011) all informed the research
267 team's understanding of the situation in Can Tho, and provided an information base to quantify
268 the WNI. Table 1 shows the chosen indicators on the basis of this understanding and the
269 workshop outcomes.

270 SUGGESTED LOCATION FOR TABLE 1

271 The dimensional weights (column 2 in Table 1) were applied as a weighted sum when
272 aggregating dimensional values into the WNI value. The indicator weights (column 4 in Table
273 1) were applied in the weighted sum when aggregating indicator values into dimensional values.
274 Water quality (Q) and Aquatic ecosystems (A) were assigned greater weight (0.3 as opposed to
275 0.1) because of their perceived relative importance by participants in the WNI workshop
276 (Moglia et al., 2010a).

277 Weighting of importance of indicators was a subjective task undertaken by researchers
278 reviewing workshop outcomes. As the sanitation situation in Can Tho City was more critical
279 than the water supply, greater weight was given to the ability to access to sanitation (0.9 vs.
280 0.1). Furthermore, the number of connections per capita was seemingly inaccurate and a
281 doubtful measure, more so than the reported percentage of the households that had access to
282 "improved sanitation services". The dissolved oxygen in the dry season was critical and
283 considered a more important indicator because values in the dry season were considerably lower

284 than in the rainy season, indicating that eco-systems suffer particular hardship in the dry
285 months. Dissolved oxygen was also considered a more pertinent indicator than the surface water
286 quality measured in terms of coliforms and was allocated a greater weight (0.8 in total) in
287 contrast to the weight for the measured coliforms (0.2).

288 The ranges (column 5 in Table 1) were used in the normalisation of data values, and calculated
289 as indicator values ranging from 0 (indicating the lower end of the range) to 100 (indicating the
290 upper end of the range). In the normalisation process, indicators were calculated such that 100
291 indicated a desirable situation, whilst 0 was particularly undesirable. In some instances, ranges
292 were inverted, e.g. an indicator value of 0 indicated a top range value. For example, in the case
293 of incidence of diarrhoeal disease, a higher rate of incidence indicated a worse outcome,
294 translated into a lower dimensional value (worse outcome gives lower dimensional value). The
295 WNI effectively normalised and standardised the information into a compatible format in which
296 to comparatively assess the “water needs” of residents of Can Tho City.

297 **4. Calculation and results**

298 The WNI has been applied at the scale of wards. A ward in Can Tho is an administrative area,
299 within a district. There are 44 wards within the 5 urban districts in Can Tho as shown in Figure
300 1, which also shows the estimated WNI scores in colours ranging from green (high score, i.e.
301 good performance) to red (low score, i.e. bad performance). Each ward has a population of
302 approximately 10,000-35,000 people. The current populations of the districts tends to vary from
303 about 80,000 people in Cai Rang to about 215,000 people in Ninh Khieu.

304 SUGGESTED LOCATION FOR FIGURE 1

305 Collated data is presented in Table 1, and on this basis, dimensional values were calculated and
306 presented in Table 2. There were some limitations in the data sets in that they did not cover all
307 of the wards, and in these cases an extrapolation process was used. This extrapolation used a
308 weighted average of wards considered most similar in geographical location, land use and other
309 pertinent factors depending on the particular ward. For example, for the purpose of the A

310 dimension, a ward next to the main river (the Mekong) was considered similar to another nearby
311 ward upstream and downstream, but not be considered similar to a ward further inland without
312 direct river frontage.

313 SUGGESTED LOCATION FOR TABLE 2

314 Pearson product-moment correlation coefficients, varying between 1 and -1, have also been
315 calculated between the dimensions in the WNI, using values in Table 2 as inputs. A correlation
316 coefficient near zero indicates very little co-variation between the two variables, whilst a higher
317 correlation coefficient closer to 1 indicates that a high/low value in one variable tends to
318 coincide with a high/low value in the other. A lower correlation coefficient perhaps closer to -1
319 indicates that a high value in one variable tends to coincide with a low value in the other (and
320 vice versa). The dimensions that have a relatively strong correlation (>0.4) with the WNI are W,
321 I and G. Perhaps not surprisingly, areas that were more urbanised had higher grade services
322 (higher W), less (average) flooding risk (F) and superior infrastructure performance (I). On the
323 other hand, these areas had higher indexes for polluted surface waters (A), likely due to the
324 discharge of untreated wastewater, stormwater runoff and industrialization.

325 **5. Discussion**

326 The application of the WNI, as described in this paper provides a novel approach to the
327 assessment of water needs across an urban area in a fast developing South East Asian regional
328 centre. Assessing water needs in this context is important for the purposes of directing the
329 attention of water planners and practitioners to more urgent and complex issues. As with any
330 approach, the reliability and accuracy of the assessment depends on the availability of data and
331 the type of analysis conducted. We have shown that by using a household survey approach, in
332 combination with surface water quality measurements, it was possible to undertake a relatively
333 rapid assessment of water sector needs in Can Tho City. This approach can be used to assess
334 water needs in any city in the world, although it can be argued that the selection of dimensions
335 and indicators may need to be adjusted on the basis of local conditions. This adaptation process

336 can be effectively achieved by means of a well established workshop process (Moglia et al.,
337 2010a). The application of the WNI to the case study site of Can Tho City has enabled an
338 exploration of a range of issues at both the district as well as at the ward scale, and it is clear
339 that analysis at both levels provides useful insights into the complex water supply and sanitation
340 needs within this city and surrounds.

341 In simplified terms, those areas that have poorer access to services, and infrastructure that is in
342 poorer condition tend to have better environmental conditions (i.e. relating to surface water, risk
343 of flooding and groundwater) and vice versa. This effect seems to even out the differences in the
344 WNI score, and explains the impacts of a variety of factors implicated in water quality and
345 supply issues for residents of Can Tho City.

346 **5.1 District WNI profiles**

347 The WNI of the districts in Can Tho City are shown in Table 3, on the basis of the average
348 values in respective wards.

349 SUGGESTED LOCATION FOR TABLE 3

350 Based on the information in Table 2 and Table 3 the following conclusions have been
351 postulated:

- 352 • In Ô Môn, the average district WNI value is approximately at the 5%-percentile lowest
353 WNI value for wards. Contributing to this, the W dimensional value in Ô Môn is close
354 to the 10%-percentile lowest value across all wards – indicating that a large proportion
355 of the “poorest access” wards are in this area. Hence, this district would benefit
356 considerably from better access to water supply and sanitation; especially as the Q
357 dimensional value for the district is also very low, relating primarily to very poor health
358 outcomes. It is premature to link the poor access as a causative factor for poor health
359 outcomes, although this issue is explored by Neumann et al. (2012) who can clearly link
360 health outcomes with type of water supply and type of sanitation. Detailed evaluation of
361 the household survey data (Neumann et al., 2012) shows that utilisation of multiple

362 water sources seems to be an indicator of a problematic water supply situation and poor
363 health outcomes, and this is aligned with conclusions from a previous study in a
364 different location (Moglia et al., 2008b, 2010b). It is suggested that a water safety
365 assessment (AusAID, 2005) be undertaken for households in this ward to explore
366 pathogen pathways, and how water safety may be improved. It is interesting to note that
367 the initial workshop did identify concerns about the situation in Ô Môn but that such
368 concerns were also disputed due to lack of detailed knowledge of the status in this area.
369 Due to the limited experience of the workshop participants, no one at the time was
370 really in a position to comment in more detail about the situation in Ô Môn.

371 • The lowest dimensional value recorded for any dimension for any of the districts is the
372 A dimensional value of 12 in Ninh Kiều. The surface water quality varies considerably
373 across the urban areas, with particular hot spots in those areas where one may expect
374 high levels of pollution from the surrounding urban landscape, and where flows are
375 limited or restricted. It seems that efforts to reduce pollution into waterways, at least in
376 some areas, is urgent in order to avoid irreparable damages to eco-systems, and reduce
377 potential health risks associated with poor surface water quality. Healthier waterways
378 ought also to provide symbolic value in the promotion of tourism in Can Tho, which is
379 a regional centre in what is often referred to as a water civilisation.

380 • A very low dimensional value of 21 was recorded in Bình Thủy for the G dimension.
381 This is consistent with the concerns raised in the workshop (Moglia et al., 2010a) about
382 over-extraction and pollution of groundwater by industry in this area. Indeed, Bình
383 Thủy is a district with significant industrial production, and it is largely recognised that
384 whilst there exists regulation regarding groundwater extraction, there are currently only
385 limited enforcement mechanisms in place. In summary, efforts should be made to help
386 provide industry with cheap and readily accessible water in a way that does not limit
387 economic development. Recycling of wastewater or basic treatment of surface water, in
388 combination with the application of eco-industrial concepts appear good alternatives.

389

390 Less severe, but also important, concerns identified were:

391 • Poor surface water quality and aquatic ecosystem condition in Ô Môn and in Cái Răng.

392 These areas are also relatively urbanised.

393 • Poor water and sanitation access, as well as water quality (for human use) in Thốt Nốt is

394 less than adequate. Thốt Nốt is an area that is similar in character to Ô Môn but where

395 the location closer to the main river may alleviate some problems. Lack of access to

396 adequate water and sanitation services in combination with poor environmental

397 condition and poor surface water quality may be a particularly bad combination.

398

399 Table 3 also shows that the WNI captured a more holistic view of the urban water systems, and

400 this can lead to unexpected results when compared to single measures such as access to water

401 and sanitation. The Ninh Kieu district had the highest W (90) and I (78) indexes, and is second

402 on Q and G. However, the district is third overall, as it has the lowest score in the A due to the

403 poor state of its waterways, with high BOD and low dissolved oxygen, as well as elevated levels

404 of other pollutants (Department of Natural Resources and Environment, 2009). This holistic

405 assessment which provides an overall assessment (the WNI index), as well as scores for

406 different indexes for each category, can then be used to identify and prioritise areas for

407 investment and action. The results in Table 2 clearly show that the different wards require

408 actions according to their outcome scores in the index, and a simple program targeting one of

409 the index areas (such as access to water) is less effective than using the same funds to target

410 different areas in different wards.

411 In terms of recommendations, the stand-out hotspot requiring the most urgent attention from

412 local planners is the Ô Môn district where all but one ward has a WNI score below 50.

413 However, the problems of Ô Môn are specific as the district appears to be relatively protected

414 against flooding damage and the groundwater situation seems relatively better than in other
415 districts.

416 **5.2 Ward WNI profiles**

417 Alexander et al. (2010) indicated that some indicators are more meaningful when applied at a
418 smaller geographical scale. In Can Tho, the relatively large size (scale) of the districts (which
419 contain a number of wards) sometimes obscured the water needs of specific areas within the
420 districts (hotspots) that significantly differ in comparison to those of the district as a whole. This
421 is because the aggregation and subsequent average of spatially variable data from smaller units
422 may smooth over extreme values, i.e., the modifiable area unit problem (Openshaw, 1984).
423 Commonly, while a district may have a relatively high score in a dimension (for example
424 groundwater condition) within the district there were wards that scored poorly against the
425 dimension. For example, the older urban centre in Ninh Kiều had a ward that was highly
426 vulnerable to flooding (Xuân Khánh). Other exceptions are depicted in Table 4.

427 SUGGESTED LOCATION FOR TABLE 4

428 The ward with the lowest WNI score (37) was in Thới Long in the Ô Môn district (see WNI
429 profile in Figure 2). This was primarily caused by the combination of poor health outcomes,
430 poor freshwater quality and lack of services, albeit having decent groundwater condition,
431 reduced flood risk and reasonable infrastructure performance. The ward with the highest WNI
432 score (63) was the An Cư ward in the Ninh Kiều district (see WNI profile in Figure 2), scoring
433 highly in all dimensions except for the Aquatic ecosystems, where it scored very poorly. This
434 clearly indicated the difference between two areas in the city: a highly urbanised and developed,
435 versus a less urbanised, suffering from pollution, and performing poorly in terms of limited
436 water and sanitation services. It is clear that the challenge that Can Tho City faces is to keep up
437 with provision of services while ramping up efforts for environmental management and
438 protection at a time of rapid population growth and economic development.

439 SUGGESTED LOCATION FOR FIGURE 2

440 The results from Figure 3 highlight once more the need for targeted action, with the Thoi Long
441 ward requiring improved water and sanitation access (W), while the An Cu ward showed
442 satisfactory performance in most aspects but has concerns in terms of aquatic system with high
443 levels of BOD. This information is not only useful for administrators who must decide on
444 infrastructure prioritisation, but it is also useful for planners. The results from Figure 3 indicate
445 that any spending in water supply and sanitation in Thoi Long must include spending on
446 wastewater treatment and stormwater infrastructure; otherwise the improvement in one index
447 (W) will lead to a decline in another (A). Planners may consider that this is a priority area for
448 action, i.e., ensuring water services in areas where poor surface water quality is endemic. In this
449 sense, the geographic characteristics within an urban area is important. The community is likely
450 to be less vulnerable in areas of the city where pollution can be more easily washed out from
451 canals and rivers (better surface water quality) and with higher elevation (reduced flooding
452 risk). Targeted management actions to alleviate the poorer water quality in these areas appear to
453 be worthwhile.

454 **5.3 General observations regarding Can Tho City**

455 Based on our assessment, Can Tho City from a water needs perspective appears to be a
456 “splintered” urban network, as described by Bakker (2010). There are islands of centralised
457 public water supply (high in W), scoring high in most dimensions except for A due to more
458 intense pollution in the highly urbanised areas. This is contrasted with the areas with
459 Community Groundwater Schemes where drinking water quality is good, but where sanitation is
460 often inadequate. The surface water quality in the entire city is a cause for real concern, but the
461 quality is variable presumably due to local water flow patterns and local pollution loads.
462 Detailed exploration of water quality data reveals that this issue is particularly acute in the dry
463 season.

464 The modern ideal of a large centralised system, which has been proposed in workshops,
465 however seems inconceivable considering the large geographical size of the city and the
466 apparent better performance of alternative water supplies in comparison to centralised piped

467 supplies in Can Tho City (Neumann et al., 2012). The more promising water supply approach of
468 using community groundwater schemes however seems limited by the apparent over-extraction
469 and/or pollution of groundwater in some parts of the city, putting into question the need for
470 more control and regulation.

471 **5.4 Observed benefits of the WNI process**

472 The WNI framework has been flexibly adapted to inform urban water resource management in
473 three study sites, with varying success (Alexander et al., 2011). This paper describes its
474 application in Can Tho City. The benefits from combining participatory procedures with
475 modelling techniques has been the sharing of knowledge and information between local experts
476 and with researchers through a simple, understandable and flexible approach to gathering data,
477 opinions and providing a means to explore contentious topics. The idea is that elicited
478 information can then be used to assist collective decision-making processes and in the
479 establishment of a collective vision for the future management of resources. Specifically, the
480 WNI workshop and related activities have helped in the following benefits, framed in the
481 language of the framework used by Jones et al. (2009):

- 482 • Normative function: it is the distinct impression that the WNI application in Can Tho
483 City has helped provide legitimacy of the assessments. This ought to increase the
484 likelihood of finding coordinated solutions with wider buy-in from important
485 stakeholders.
- 486 • Substantive function: the WNI application, and in particular the WNI workshop, helped
487 initiate the sector review and to identify data sources related to pertinent topics
488 (Neumann et al., 2011). Because of the increased buy-in into the process, it was also
489 relatively easier to access data to support subsequent review and analysis.
- 490 • Instrumental function: perhaps the greatest benefit of the WNI application in Can Tho
491 has been its function of creating a common language (i.e., dimensions, which have been
492 clearly defined in terms of their scope). The process has also helped initiate ongoing

493 collaboration in the project, and there is a strong sense that there is now a much greater
494 acknowledgment of the need to collaborate and communicate between sectors,
495 department and organisations.

496 In terms of outcomes of the activity from a participatory modelling perspective, there has been a
497 clear sense of building collective knowledge and finding new ways of understanding the urban
498 water system in Can Tho, for a variety of stakeholders. There is also a good likelihood of the
499 activity evolving beyond the scope of this project.

500 **5.5 Dealing with geographical information bias**

501 This research has illustrated how the WNI process can be used at an urban scale to identify
502 areas that require the most urgent attention in order to address local water needs. The evidence
503 base is householder surveys and surface water quality measurements, and such data ought to be
504 easy to collect and/or accessed by urban water practitioners and planners in most urban centres.

505 It should be noted however that surface water quality monitoring data may be of variable
506 reliability, in particular when there is significant temporal and/or spatial variability in
507 measurement results. Hence caution in dependence on only one source of data is recommended.

508 However, by using these sources of data, the WNI assessment process provides a transparent
509 and more democratic way to highlight the water issues and supply concerns across an urban
510 area.

511 Interestingly, it was noted by participants and observed by researchers in the WNI workshop
512 (Moglia et al., 2010a) that most participants had limited knowledge of issues in more peripheral
513 parts of the city, and consequently attention was often skewed toward areas about which details
514 were better known. In fact, whilst Ô Môn (the district with lowest WNI score) was noted in the
515 workshop as one area of concern, that judgment was also questioned strongly by other
516 participants. Hence, uncertainty regarding the relative needs of different areas can be used to
517 question the need for actions in these same areas. In fact when practical actions were discussed,
518 the focus was mostly on parts of the cities that were well established and where the needs were
519 more familiar. It can be hypothesised that, in particular in cultures with a low tolerance for

520 ambiguity and uncertainty (Hofstede, 2001; Hofstede and Hofstede, 2004), such a bias in
521 information availability will have an impact on investment decisions. Vietnam has not been
522 assessed in terms of its cultural disposition towards uncertainty avoidance.

523 Such bias that is caused by limited information and experience may be one of the causal drivers
524 for the well-known dilemma of provision of adequate services in the central areas of developing
525 cities whilst services remain inadequate in the outer or peri-urban settlements (Bakker, 2010;
526 Gerlach, 2008; Swyngedouw, 2004). At times, these areas of poor distribution can face water
527 prices as much as 10, 20 or 400 times higher than those centrally supplied (Jouravlev, 2004).
528 The authors believe that the WNI provides a way to address this bias if used to direct actions
529 and attention at various scales and is applicable to most situations.

530 **5.6 Lessons for future applications of the WNI**

531 One may view the WNI as providing a common frame of reference, where each geographical
532 location in the in the assessment is mapped against a six dimensional space. A couple of lessons
533 regarding the use of WNI are as follows: both consideration of the temporal scale and the
534 variability in aggregation practices are important; and creating a space for a systems perspective
535 as part of day-to-day business is a worthwhile but challenging task.

536 A limitation of the WNI as it has been applied to date is that it is limited in the temporal scale.
537 A longitudinal study, tracking the WNI over time, would address this concern and is likely to
538 provide some key insights into dynamics and drivers in the urban water system. It is
539 acknowledged that the ability to undertake such a study will be limited by the opportunity to
540 collect data of reasonable quality, such as by means of household surveys and water quality
541 measurements. Data from a longitudinal WNI study may furthermore provide a dataset that may
542 help in the parameterisation of an Agent-Based Model (Smajgl et al. 2011) representing the
543 dynamic nature of an urban system, as per Moglia et al. (2010b).

544 An important issue to consider in the application of the WNI is the variability within each
545 location. In this study, there is considerable variability within some of the wards and in such

546 situations, the WNI dimensional values represent statistical means with higher variability. Other
547 wards are homogeneous, and in those situations WNI dimensional values represent a dominant
548 situation. This makes aggregation more difficult for some of the areas. For the areas with greater
549 variability, we have found it to be useful to collect complementary qualitative information such
550 as through interviews at a household scale. This allows for better understanding the underlying
551 factors and drivers that creates the situations.

552 Stakeholders tend to have a very sectoral focus, and it is a rare occurrence to find an
553 organisation, or even an individual that has adopted a systems perspective in their day to day
554 operations. In workshops however, individuals and organisations can clearly gain strong
555 insights by adopting a systems perspective. It will be important to support at least one local
556 institution to adopt a systems perspective in their day to day operations. This may perhaps be
557 achieved by means of knowledge brokers or boundary organisations

558 **6. Conclusions**

559 This paper describes the application of the WNI at an urban scale to the regional centre of Can
560 Tho City, Vietnam, located at the heart of the Mekong delta. The WNI provides an approach for
561 rapid and interdisciplinary assessment of an urban water system that has an empirical
562 foundation. The approach incorporates biophysical, economic and social drivers linking water,
563 environment and poverty, which can be used to identify systemic water issues and identification
564 of hotspots that require attention by local authorities. The data required for the application in
565 Can Tho City, i.e., a household survey and water quality monitoring data, ought to be widely
566 available in most cities; although in many cases a household survey may need to be carried out
567 in situ by researchers. Several key functions of the WNI application process relates to
568 stakeholder engagement outcomes, and in particular the emergent common language and
569 integrated perspective amongst stakeholders. The WNI framework further provides a common
570 frame of reference, i.e., a coordinated system with several dimensions that allows stakeholders
571 to measure progress in urban water management performance and capacity into the future. In
572 the application in Can Tho City, it also emerged that the local stakeholders may be blinded to

573 issues in certain areas, due to their limited knowledge about parts of the city with which they
574 were unfamiliar. Such blind spots are likely to exist because of the inherent social and economic
575 structures in the city, and may entrench existing inequities relating to water and sanitation
576 access as well as indicating different environmental management practices. The Water Needs
577 Index provides a framework for limiting the biases that water planners and stakeholders may
578 have, and the authors believe that its application can provide real value in future urban water
579 management and planning.

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590 **References**

- 591 Abu Zahra, B.A.A., 2001. Water crisis in Palestine. *Desalination* 136(1-3) 93-99.
- 592 Alexander, K.S., Miller, C., Jovanovic, T., Moglia, M., 2009a. Tigum-Aganan Watershed
593 Management Project, Part 2: Developing a Water Needs Index, Climate Adaptation
594 National Research Flagship Report. CSIRO: Canberra, Australia.
- 595 Alexander, K.S., Moglia, M., Burn, S., 2009b. Informing future investment decisions for water
596 and sanitation projects in the asia pacific by integrating statistical and qualitative
597 information, 18th World IMACS Congress and International Congress on Modelling

598 and Simulation: Interfacing Modelling and Simulation with Mathematical and
599 Computational Sciences, MODSIM09: Cairns, QLD, pp. 2856-2862.

600 Alexander, K.S., Moglia, M., Miller, C., 2010. Water Needs Assessment: learning to deal with
601 scale, subjectivity and high stakes. *Journal of Hydrology* 388(3-4) 251–257.

602 Alexander, K.S., Moglia, M., Tjandraatmadja, G.T., Nguyen, M., Larson, S., Trung, N.H.,
603 Barkey, R.A., 2011. Evaluation of Water Needs Index case studies, In: Chan, F.,
604 Marinova, D., Anderssen, R.S. (Eds.), MODSIM2011, 19th International Congress on
605 Modelling and Simulation. Modelling and Simulation Society of Australia and New
606 Zealand: Perth, Australia, pp. 2896-2872.

607 AusAID, 2005. Safe water guide for the Australian aid program 2005. AusAID: Canberra.

608 Bakker, K., 2010. Privatizing water: governance failure and the world's urban water crisis.
609 Cornell University, New York, U.S.

610 Barnett, J., Lambert, S., Fry, I., 2008. The hazards of indicators: insights from the
611 environmental vulnerability index. *Annals of the Association of American Geographers*
612 98(1) 102–119.

613 Barreteau, O., 2003. Our Companion Modelling Approach. *Journal of Artificial Societies and*
614 *Social Simulation* 6(2).

615 Creswell, J.W., 2009. Mapping the field of mixed methods research. *Journal of Mixed Methods*
616 *Research* 3(2) 95–108.

617 Daniell, K.A., White, I., Ferrand, N., Ribarova, I.S., Coad, P., Rougier, J.E., Hare, M., Jones,
618 N.A., Popova, A., Rollin, D., Perez, P., Burn, S., 2010. Co-engineering participatory
619 water management processes: Theory and insights from Australian and Bulgarian
620 interventions. *Ecology and Society* 15(4).

621 Department of Natural Resources and Environment, 2009. Report on Environment Quality
622 Monitoring Can Tho City 10 Years (1999-2008) Center of Natural Resources and
623 Environment Monitoring and Can Tho Department of Natural Resources and
624 Environment: Can Tho City, Vietnam.

625 Dragon Institute, 2009. Climate Change Impacts and Vulnerabilities Assessment for Can Tho
626 City. Asian Cities Climate Change Resilience Network Program: Can Tho.

627 Dray, A., Perez, P., Jones, N., Le Page, C., D'Aquino, P., White, I., Auatabu, T., 2006. The
628 AtollGame Experience: From Knowledge Engineering to a Computer-Assisted Role
629 Playing Game. *Journal of Artificial Societies and Social Simulation* 9(1).

630 Dudgeon, D., 2000. Large scale hydrological changes in Tropical Asia: Prospects for riverine
631 biodiversity. *BioScience* 50 (9) 793 -806.

632 Funtowicz, S.O., Ravetz, J.R., 1993. Science for the post-normal age. *Futures* 25 739–755.

633 Gephart, N., Blate, G., McQuistan, C., Thompson, C., 2010. New blood Greater Mekong new
634 species discorives in 2009. WWF.

635 Gerlach, E., 2008. Regulating water services for Nairobi's informal settlements. *Water Policy*
636 10 531–548.

637 Grohmann, A., 2009. How urban areas can contribute towards easing the world-wide water
638 crisis. *Beitrag der urbanen räume zur linderung der weltweiten wasserkrise:
639 notwendigkeiten und spielräume* 150(7-8) 576-586.

640 Henriques, S., 2011. Too little, too hard to find: Addressing the global water crisis. *IAEA*
641 *Bulletin* 53(1) 3-5.

642 Herbst, S., Benedikter, S., Koester, U., Phan, N., Berger, C., Rechenburg, A., Kistemann, T.,
643 2009. Perceptions of water, sanitation and health: a case study from the Mekong Delta,
644 Vietnam. *Water Science & Technology* 60(3) 699-707.

645 Hofstede, G., 2001. Culture's Consequences, Comparing Values, Behaviors, Institutions, and
646 Organizations Across Nations. Sage Publications, Thousand Oaks, CA.

647 Hofstede, G., Hofstede, G.-J., 2004. Cultures and Organizations: Software of the Mind.
648 McGraw-Hill, New York, US.

649 Hung, D.T., Bang, N., Giang, P., 1998. Groundwater Resources of the Mekong Delta and
650 Studying Areas. The Southern Geological Division of Hydrogeology and Engineering
651 Geology.

652 IUCN, 2011. Groundwater in the Mekong Delta - Discussion Paper, Mekong Water Dialogues.
653 Ministry for Foreign Affairs of Finland.

654 Jones, N.A., Perez, P., Measham, T.G., Kelly, G.J., d'Aquino, P., Daniell, K.A., Dray, A.,
655 Ferrand, N., 2009. Evaluating Participatory Modeling: Developing a Framework for
656 Cross-Case Analysis. *Environmental Management* 44(6) 1180–1195.

657 Jouravlev, A., 2004. Drinking water supply and sanitation services on the threshold of the XXI
658 century: Santiago, Chile.

659 Maheepala, S., Blackmore, J., Diaper, C., Moglia, M., Sharma, A., Kenway, S., 2010. Integrated
660 Urban Water Management Planning Manual. Water Research Foundation, Denver, CO.

661 Moglia, M., Alexander, K.S., Cook, S., Sullivan, C., Lane, B., Lipkin, F., 2008a. Regional and
662 Country Scale Water Resource Assessment; Informing Investments in Future Water
663 Supply in the Asia Pacific Region – a Decision Support Tool Water for a Healthy
664 Country National Research Flagship Report Series. CSIRO: Melbourne, Australia.

665 Moglia, M., Burn, S., Tjandraatmadja, G., 2009. Vulnerability of water services in Pacific
666 Island countries: combining methodologies and judgment. *Water Science & Technology*
667 60(6) 1621–1631.

668 Moglia, M., Cook, S., Nguyen, M., Trung, N., Paddon, M., Lipkin, F., Meharg, S., 2010a. Water
669 risk index workshop in Can Tho, Vietnam. Case study on Urban Water Systems in Can
670 Tho, Vietnam. CSIRO Climate Adaption Flagship, : Melbourne, Australia.

671 Moglia, M., Perez, P., Burn, S., 2010b. Modelling an urban water system on the edge of chaos.
672 *Environmental Modelling & Software* 25(12) 1528-1538. doi:
673 10.1016/j.envsoft.2010.05.002.

674 Moglia, M., Perez, P., Burn, S., 2008b. Water troubles in a Pacific atoll town. *Water Policy*
675 10(6) 613–637.

676 Moglia, M., Perez, P., Burn, S., 2012. Assessing the likelihood of realizing idealized goals: the
677 case of urban water strategies. *Environmental Modelling & Software* 35 50-60.
678 10.1016/j.envsoft.2012.02.005

679 Molle, F., Mollinga, P., 2003. Water poverty indicators: conceptual problems and policy issues.
680 *Water Policy* 5 529–544.

681 Neumann, L., Moglia, M., Cook, S., Nguyen, M., Sharma, A.K., Nguyen, T., 2012. Water use
682 and sanitation in Can Tho City: challenges of urbanisation in the Mekong Delta. *Urban*
683 *Water Journal* In Press.

684 Neumann, L., Nguyen, M., Moglia, M., Cook, S., Lipkin, F., 2011. Urban Water Systems in
685 Can Tho, Vietnam: Understanding the current context for climate change adaptation,
686 Water for a Healthy Country National Research Flagship Report Series. CSIRO Land
687 and Water: Melbourne, Australia.

688 Openshaw, S., 1984. The Modifiable Areal Unit Problem. Geo Books, Norwich, U.K.

689 Ribarova, I., Assimacopoulos, D., Jeffrey, P., Daniell, K.A., Inman, D., Vamvakieridou-
690 Lyroudia, L.S., Melin, T., Kalinkov, P., Ferrand, N., Tarnaki, K., 2011. Research-
691 supported participatory planning for water stress mitigation. *Journal of Environmental*
692 *Planning and Management* 54(2) 283-300.

693 SIURP, 2010. Adjustment of Master Plan of Can Tho City to Year 2030, Synthesis Report.
694 Southern Institute of Urban and Rural Planning, Ministry of Construction: Ho Chi Minh
695 City, Vietnam.

696 Smajgl, A., Brown, D.G., Valbuena, D., Huigen, M.G.A., 2011. Empirical characterisation of
697 agent behaviours in socio-ecological systems. *Environmental Modelling & Software*
698 26(7) 837-844.

699 Sullivan, C., 2002. Calculating a Water Poverty Index. *World Development* 30(7) 1195-1210.

700 Sullivan, C., Meigh, J., 2005. Targeting attention on local vulnerabilities using an integrated
701 index approach: the example of the climate vulnerability index. *Water Science and*
702 *Technology* 51(5) 69-78.

703 Swyngedouw, E., 2004. Social Power and the Urbanisation of Water: Flows of Power. Oxford
704 University Press, New York, US.

705 Thanh, D.V., 2008. Household switching behaviour in the use of groundwater in the Mekong
706 Delta, Vietnam. Economy and Environment Program for Southeast Asia.

- 707 Timmer, D.K., de Loë, R.C., Kreutzwiser, R.D., 2007. Source water protection in the Annapolis
708 Valley, Nova Scotia: Lessons for building local capacity. *Land Use Policy* 24(1) 187-
709 198.
- 710 Tuan, L.A., Hoanh, C.T., Miller, F., Sinh, B.T., 2007. Floods and Salinity Management in the
711 Mekong Delta, Vietnam, In: Be, T.T., Sinh, B.T., Miller, F. (Eds.), *Challenges to*
712 *Sustainable Development in the Mekong Delta: Regional and National Policy Issues*
713 *and Research Needs.*
- 714 UNDP, 2006. Human Development Report. Beyond scarcity: Power, poverty and the global
715 water crisis. United Nations: New York.
- 716 Vörösmarty, C.J., Green, P., Salisbury, J., Lammers, R.B., 2000. Global Water Resources:
717 Vulnerability from Climate Change and Population Growth. *Science* 289(5477) 284-288
718 DOI: 10.1126/science.289.5477.284
- 719 Wakidaa, F.T., Lerner, D.N., 2004. Non-agricultural sources of groundwater nitrate: a review
720 and case study. *Water Research* 39 3-16.

721 **1. Figure captions**

722 **Figure 1. Location of surveyed wards in Can Tho City.**

723 **Figure 2: WNI profiles of the highest and lowest scoring wards in Can Tho City**

724 **2. Table captions**

725 **Table 1: Chosen indicators (input) for the WNI application in Can Tho City**

726 **Table 2: WNI calculated for the wards of Can Tho**

727 **Table 3: WNI values for the districts of Can Tho City**

728 **Table 4: Exceptions to district scale recommendations**

Figure 1

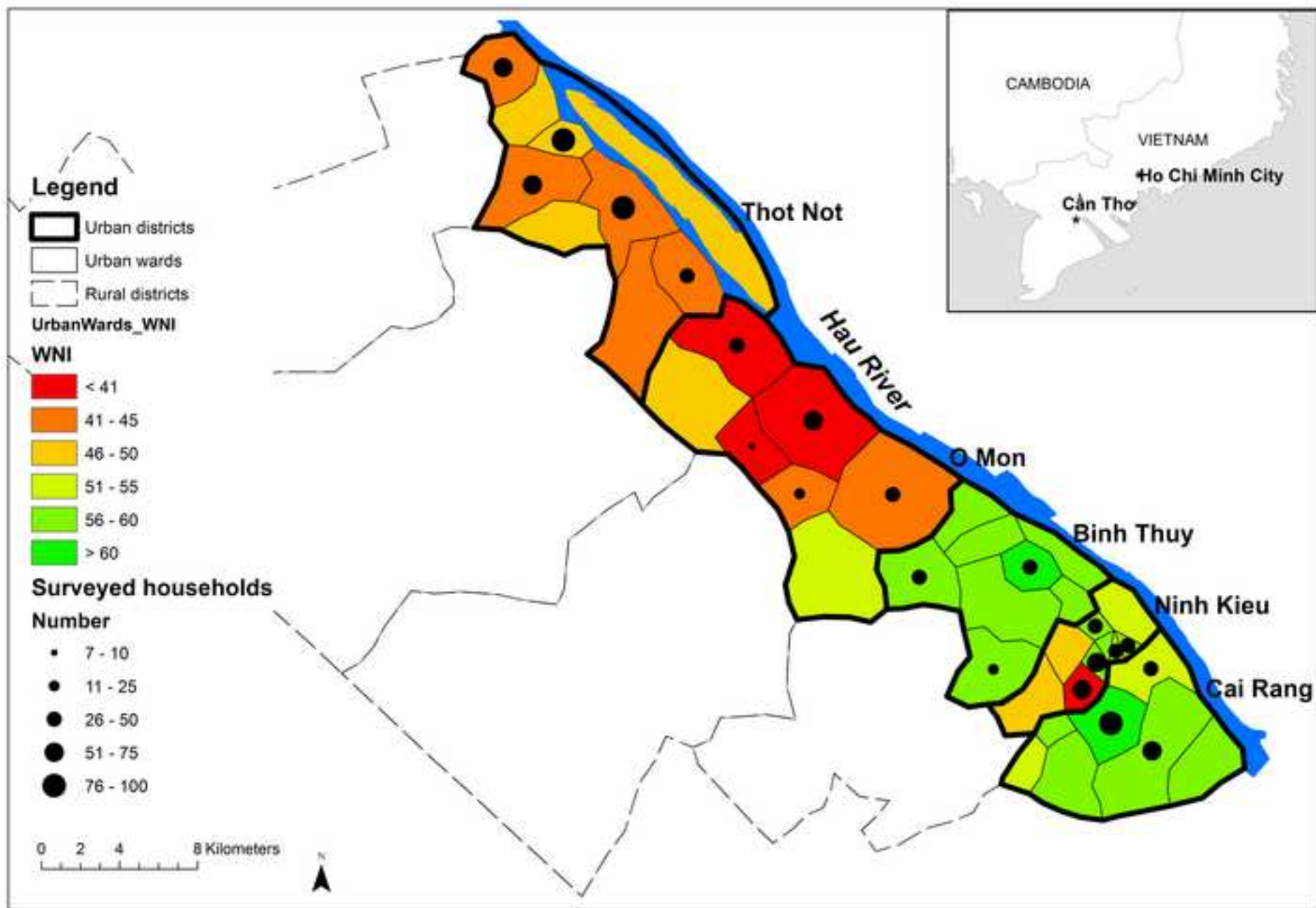
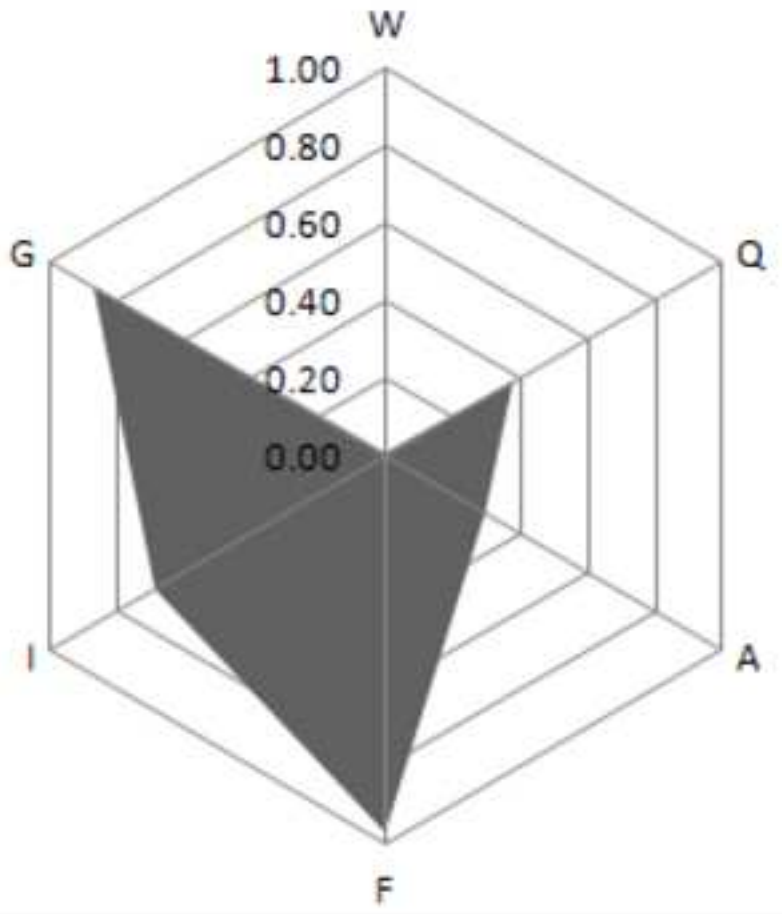
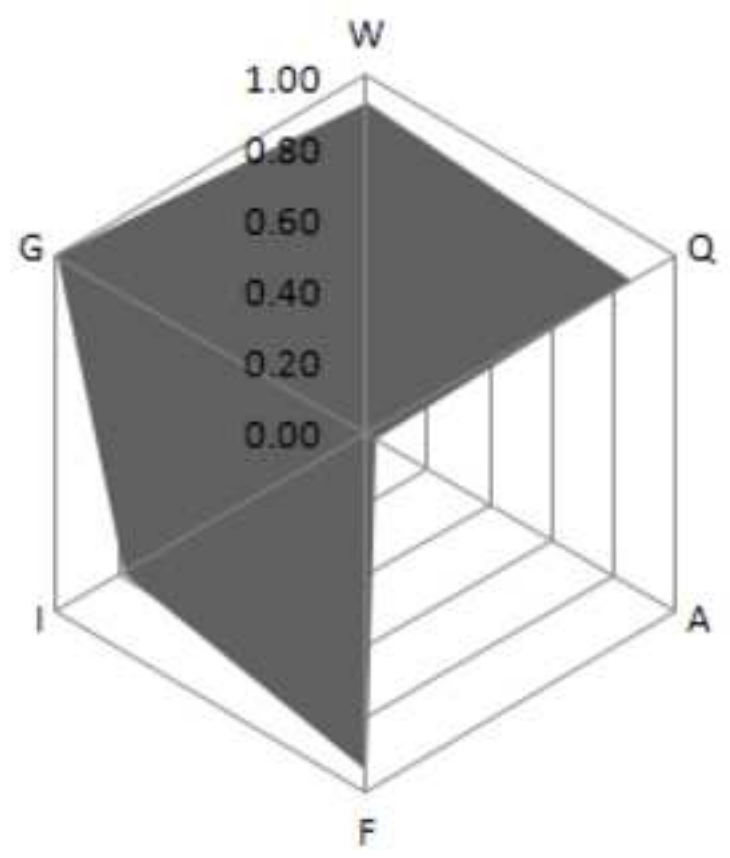


Figure 2

Thời Long (37)



An Cư (63)



ACCE

Table 1: Chosen indicators (input) for the WNI application in Can Tho City

WNI dimension	Dimensional Weight	Chosen indicators	Indicator weight	Range
Water & sanitation Access (W)	0.1	Connections per capita to piped water supply or community based groundwater schemes ^d	0.1	0.03-0.54
		Percentages of householders with lack of access to improved sanitary services, i.e. this means survey responses <i>Other</i> and <i>Hanging Toilet</i> ^e	0.9	0-52% ^a
Quality of Accessed Water (Q)	0.3	Incidence of water related illness, i.e. percentage of households reporting to have been sick with diarrhoeal disease ^e	1.0	0-19% ^b
Aquatic ecosystems (A)	0.3	Dissolved Oxygen measured in mg/l – measured in January to July 2011 (dry season) ^f	0.7	3-8 ^c
		Dissolved Oxygen measured in mg/l – measured in July to December 2011 (rainy season) ^f	0.1	
		Surface water quality measured in terms of Total Coliform (MPN/100ml) ^f	0.2	930-51,150
Flooding (F)	0.1	Percentage of households who have had their houses flooded ^e	1.0	6-49%
Infrastructure performance (I)	0.1	Percentage of the households reporting that the pressure is inadequate, and or have supply for less than 18 hours of the day ^e	1.0	0-64%
Groundwater issues (G)	0.1	Percentage of households reporting depletion and/or pollution of groundwater resources ^e	1.0	0-90%

^a Note: The range for the lack of sanitation access has been defined on the based on the range of values, but excluding two outliers. Taking into account these two outliers, the observed range is 0-67%.

^b Note: The range for the incidence of water related disease has been calculated after removing two outliers. Taking into account these two outliers, the observed range is 0-37.5%.

^c Note: The range for the Dissolved Oxygen has been defined on the basis of what is the expected impact on ecosystems rather than what is observed in the range of values. The true range of values is 2.12-5.78. Higher values indicate a healthier water environment.

^d Note: Data collected from the WSSC and the CCWS in 2011, by the Can Tho University.

^e Note: Data collected by means of household survey in Can Tho of 1200 households.

^f Note: Data collected from DONRE in 2011 by the Can Tho University

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Table 2: WNI calculated for the wards of Can Tho

Ward	District	W*	Q*	A*	F*	I*	G*	WNI
Cái Khế	Ninh Kiều	92	69	26	73	77	73	53
An Hòa**		90	63	11	58	78	95	60
Thới Bình		91	60	11	70	87	97	54
An Nghiệp		92	69	11	67	81	84	56
An Cư**		93	86	3	94	78	100	56
An Hội**		93	57	6	81	96	100	63
Tân An**		78	42	20	81	100	20	56
An Lạc		85	60	5	85	88	59	47
An Phú**		93	77	3	88	76	98	51
Xuân Khánh**		90	66	2	0	67	26	60
Hưng Lợi**		92	78	12	42	57	24	39
An Khánh		94	70	6	50	67	59	49
An Bình		80	78	36	35	62	19	50
An Thới**	Bình Thủy	94	90	41	66	50	20	60
Bình Thủy		88	78	41	46	67	33	62
Trà Nóc		52	85	42	69	64	15	59
Long Hòa		65	89	41	60	62	22	58
Long Xuyên**		37	100	38	65	55	26	60
Thới An Đông**		40	100	40	75	57	12	60

Trà An		55	95	41	68	60	17	60
Bùi Hữu Nghĩa		65	89	41	60	62	22	60
Châu Văn Liêm**	Ô Môn	45	0	40	84	69	77	41
Thới Hòa		21	0	39	81	71	84	39
Thới Long		1	38	30	97	69	87	37
Long Hưng		53	0	43	59	76	86	46
Thới An		21	6	43	89	69	84	40
Phước Thới**		28	75	37	86	69	0	41
Trường Lạc		35	0	38	85	69	38	52
Lê Bình		69	59	36	64	67	38	56
Hưng Phú**		75	84	24	56	70	93	52
Hưng Thạnh	Cái Răng	53	77	40	29	67	14	62
Ba Láng		57	70	40	83	61	44	51
Trường Thạnh		64	80	40	42	68	54	57
Phú Thứ**		80	40	44	100	67	62	59
Tân Phú		66	59	44	64	67	38	56
Thốt Nốt**		Thốt Nốt	63	6	46	33	83	96
Thới Thuận	50		48	43	71	42	12	43
Trung Nhứt**	22		53	40	92	0	92	45
Thuận An	2		52	40	83	42	92	48

Thanh Hoa		1	26	42	80	42	100	49
Thuận Hưng		59	57	36	68	42	51	43
Tân Lộc		44	29	46	63	42	72	50
Trung Kiên		47	29	46	64	42	30	45
Tân Hưng		26	47	40	83	55	69	41

*Note: some of these numbers have been estimated based on extrapolation. The extrapolation has been based on averaging values based on surrounding areas.

**Note: rows in dark grey signify wards where the WNI dimensions have been established without extrapolation, and rows in lighter grey signify wards where the WNI dimensions have been established with extrapolation in only one of the underlying dimensions.

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Table 3: WNI values for the districts of Can Tho City

	W	Q	A	F	I	G	WNI
Ô Môn	29	17	39	83	70	65	41
Thốt Nốt	35	38	42	71	43	68	46
Ninh Kiều	90	67	12	63	78	66	53
Cái Răng	66	67	38	63	67	49	56
Bình Thủy	62	91	41	64	60	21	60

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Table 4: Exceptions to district scale recommendations

District	Ward	Significant exception
Ô Môn	Phước Thới	Poor groundwater condition (I)
Cái Răng	Phú Thứ	Poor water quality (Q)
Cái Răng	Hung Phú	Poor surface water quality (A)
Cái Răng	Hung Thạnh	High flood risk (F)
Bình Thủy	Long Xuyên and Thới An Đông	Poor water and/or sanitation access (W)
Thốt Nốt	Trung Nhứt	Poor infrastructure performance (I)
Thốt Nốt	Thới Thuận	Poor groundwater condition (G)
Thốt Nốt	Thốt Nốt	Poor water quality (Q)
Ninh Kiều	Xuân Khánh	High flood risk (F)
Ninh Kiều	Tân An	Poor water quality (Q)
Ninh Kiều	Tân An, Xuân Khánh, Hưng Lợi and An Bình	Poor groundwater condition (I)

We have undertaken a case study of the Water Needs Index.

The case study site is in Can Tho City, in the Mekong Delta of Vietnam.

The Water Needs Index maps six dimensions, relating to a socio-technical and biophysical aspects.

The method has been shown to support Integrated Urban Water Management.

The Water Needs Index can help planners to tackle information black spots.

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