Indicators of Water State and Trajectories

Charles J. Vörösmarty…..and numerous colleagues

the City College of New York

CUNY The City University of New York

Water Resources in Developing Countries

ICTP, Trieste ITALY 10 May 2009

Pleas, complaints on indicators…*heard many times*

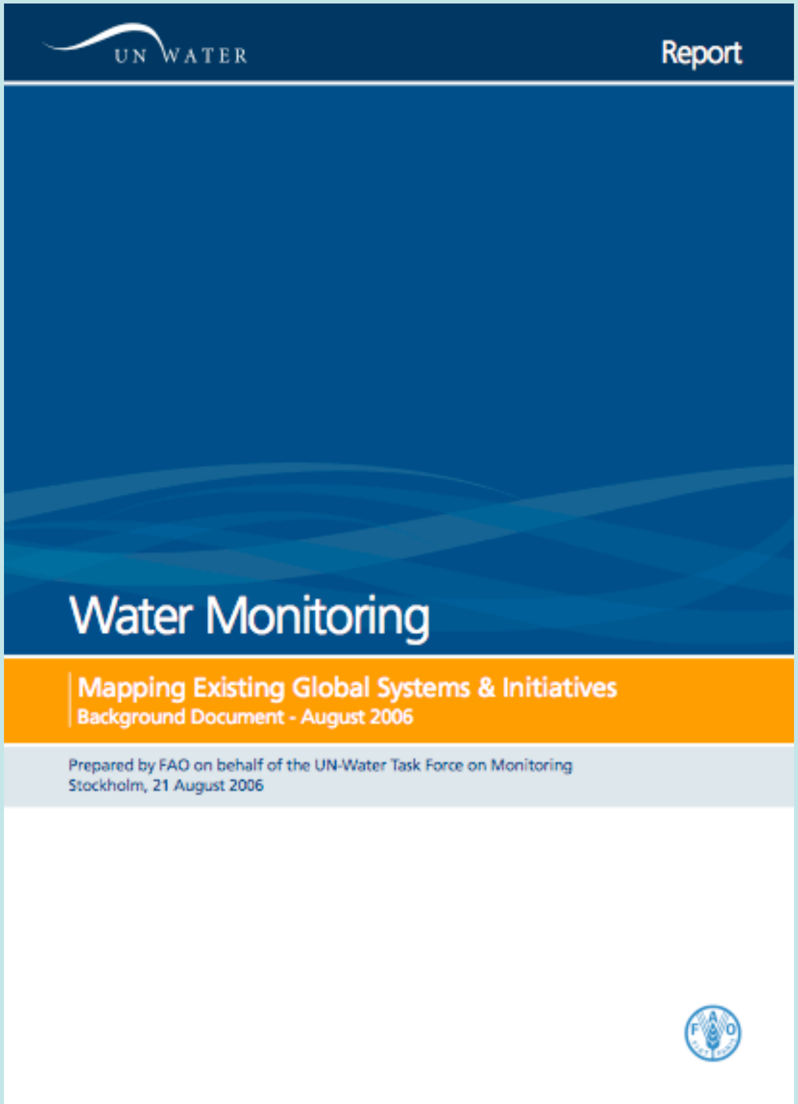
- WWDR-1 and 2 --long lists of potential indicators *(>150, 66 respectively)*
- Tables highly fragmentary across countries
- Poor integration across chapters
- Some address H_2O directly, others only tangentially
- Recycled from other sources but few unique value-added products
- Similar issues raised in many other assessments of indicators & monitoring
- ***So…the WWDR "report card series" provides:***

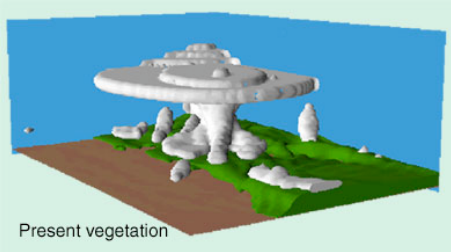
  No time series of report card grades

Innovation-averse?

- “irregular updating”, “key information still missing”, “some monitoring systems …. of little use”, “monitoring systems poorly described”

- ***And then the statement “impressive progress using global spatial information”***



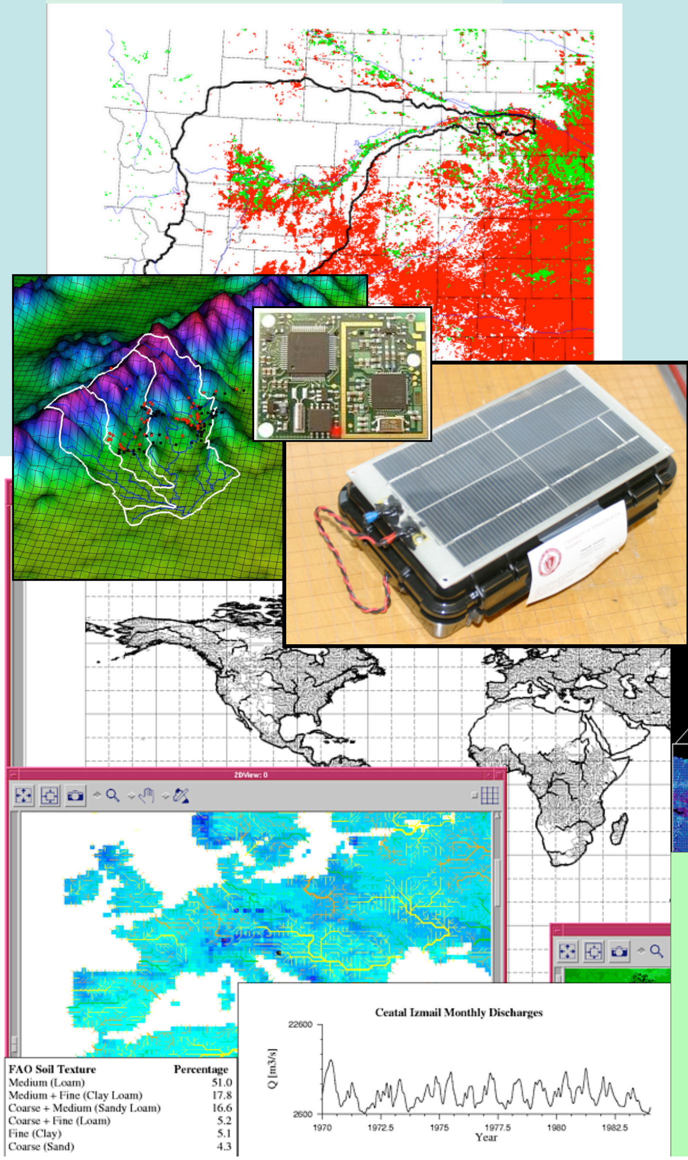


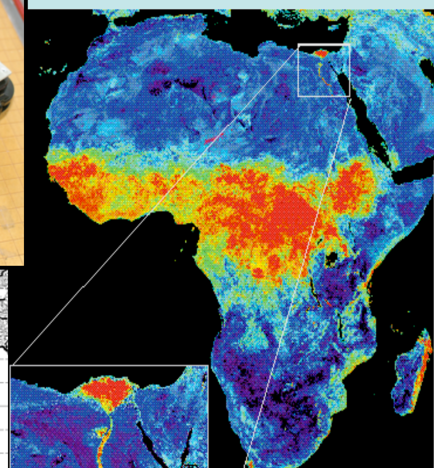
Contributions from Earth System Science

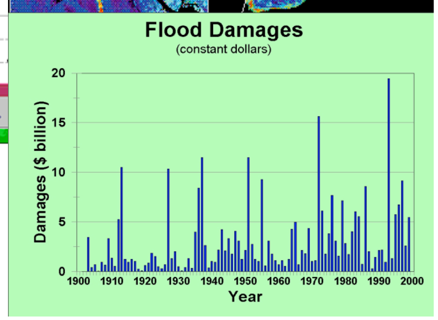
- Augmenting *in situ* networks in severe decline
- Operational satellite-based monitoring of the hydrosphere
- Simulation models and data analysis tools (NWP-4DDA, GCMs, RCMs, ESMs)
- Geo-referenced social science data

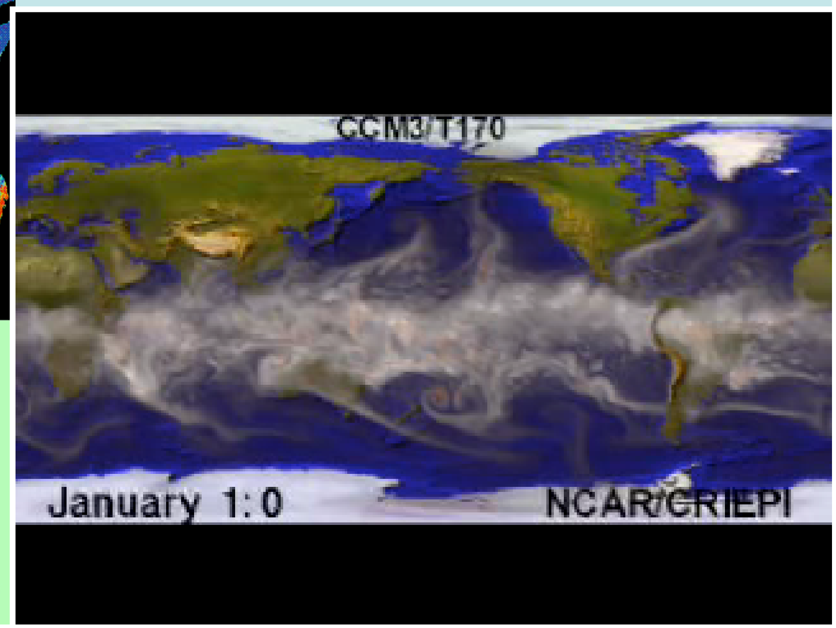
…are creating new ways to view the "global water crisis"

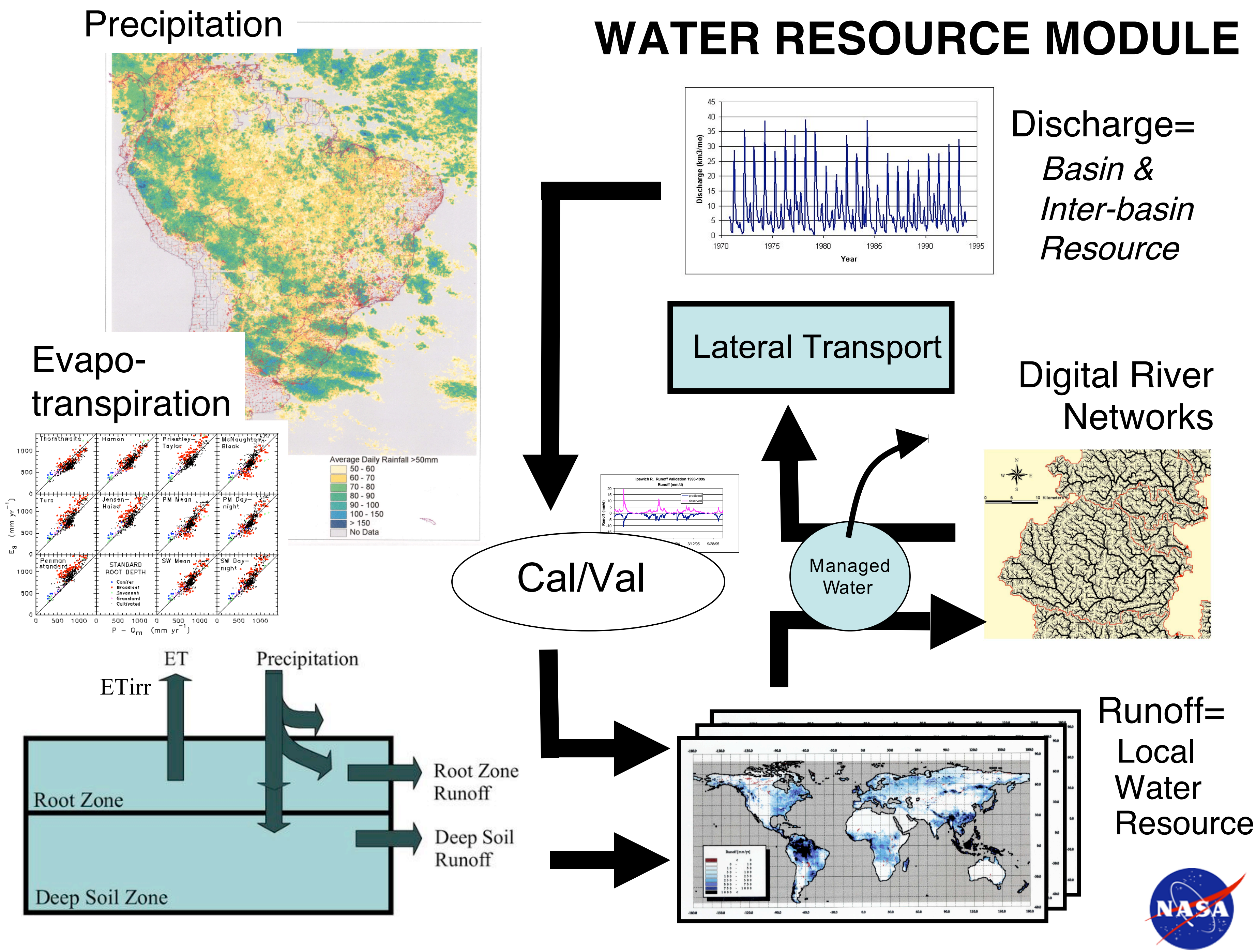
…to inform policy and improve management





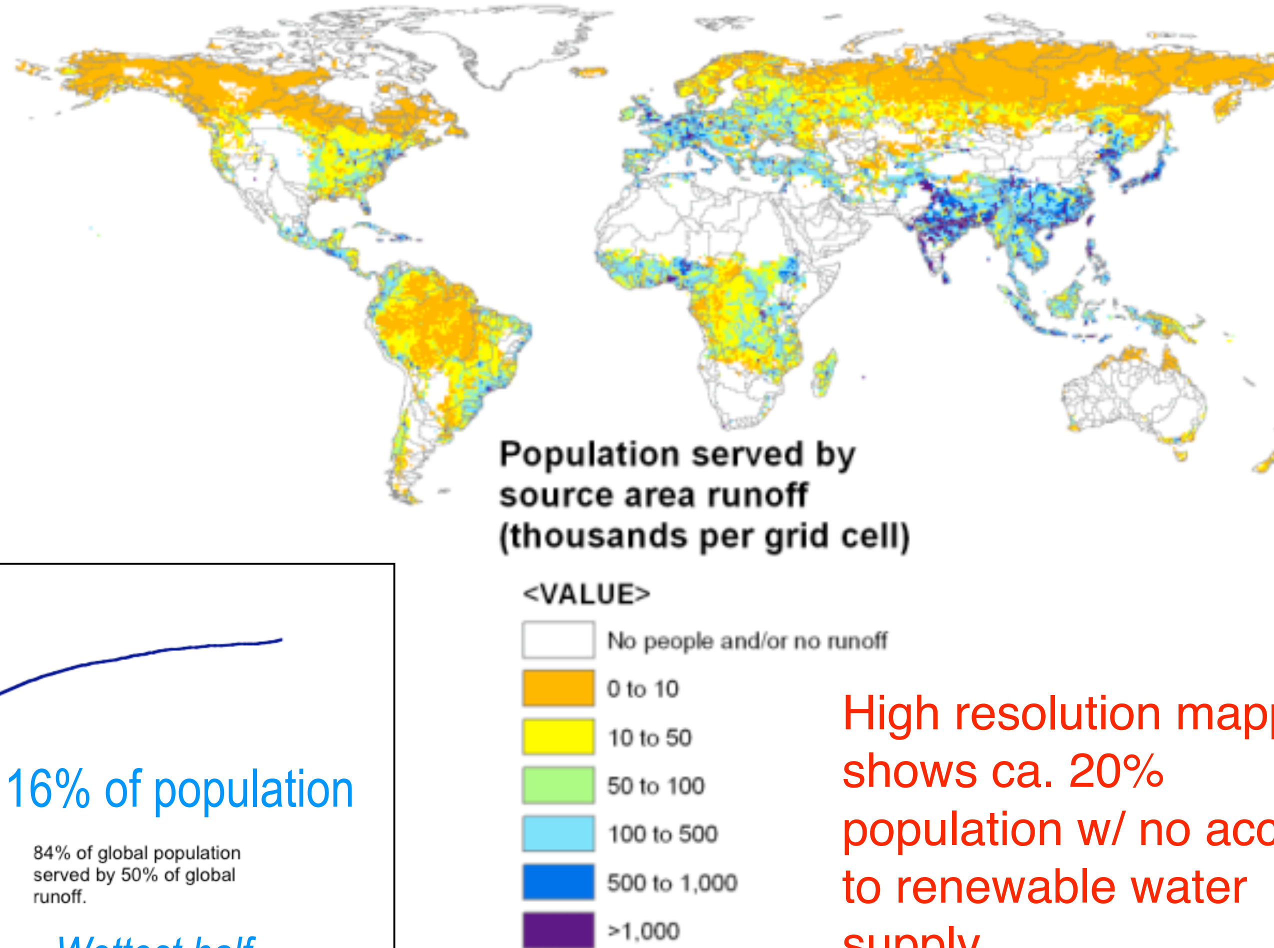




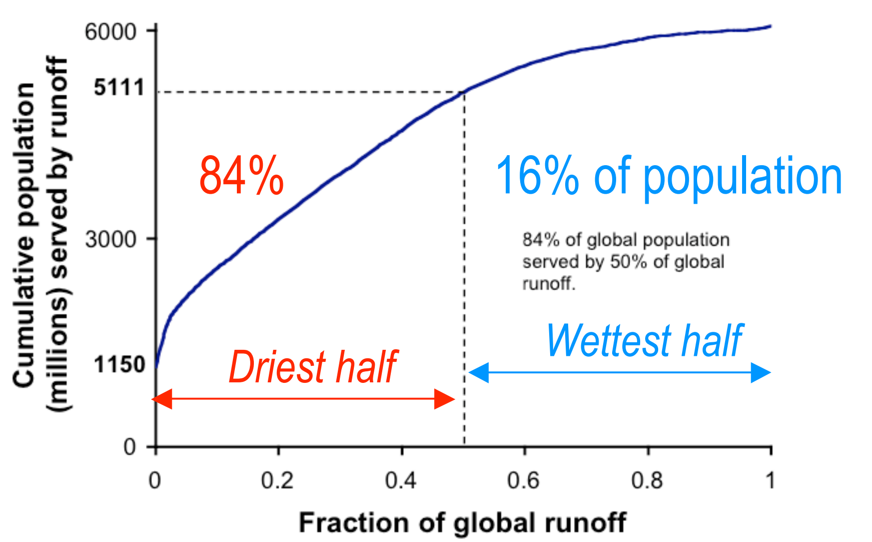

WATER RESOURCE MODULE
Precipitation
Average Daily Rainfall >50mm
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
100 - 150
> 150
No Data
Evapo-
transpiration
Discharge=
Basin &
Inter-basin
Resource
Discharge (km3/mo)
Year
Lateral Transport
Digital River
Networks
Cal/Val
Managed
Water
Ipswich R. Runoff Validation 1993-1995
ET
ETirr
Precipitation
Root Zone
Root Zone
Runoff
Deep Soil
Runoff
Deep Soil Zone
Runoff=
Local
Water
Resource
NASA

Humans Interacting w/ the Global Water Cycle--

The Picture Today



High resolution mapping shows ca. 20% population w/ no access to renewable water supply



- Importance of upstream source areas: note Amazon/S. Asian contrast
- Notion of tradeoffs w/in basin

Vörösmarty et al. (2005), Millennium Assessment, Conditions & TrendsWorking Group

Distinctions between Climate/Climate Variability and Hydrology/Hydrological Variability

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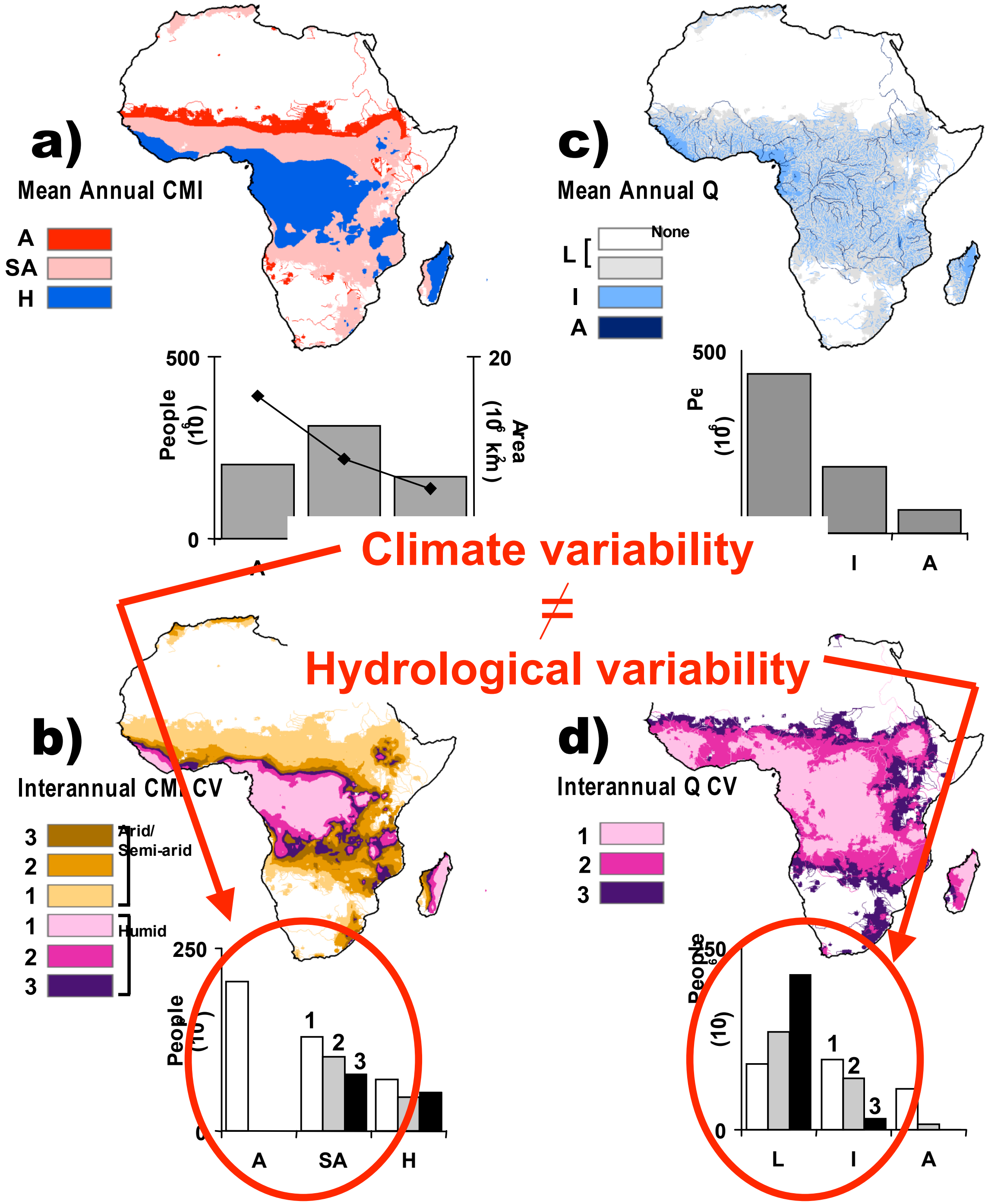
The Role of River Corridors



Explanation

Mean Annual Climate Moisture Index (CMI) Classes:

- **A** Arid (-1 to -0.6)
- **SA** Semi-arid (-0.6 to 0)
- **H** Humid (0 to 1)

Mean Annual Discharge (Q) Classes:

- **L** Limited (<0.1 km^3/yr)
- **I** Intermediate (0.1 to 10 km^3/yr)
- **A** Abundant (>10 km^3/yr)

Interannual Coefficient of Variability (CV) Classes:

- **1** <0.25
- **2** 0.25 to 0.75
- **3** >0.75

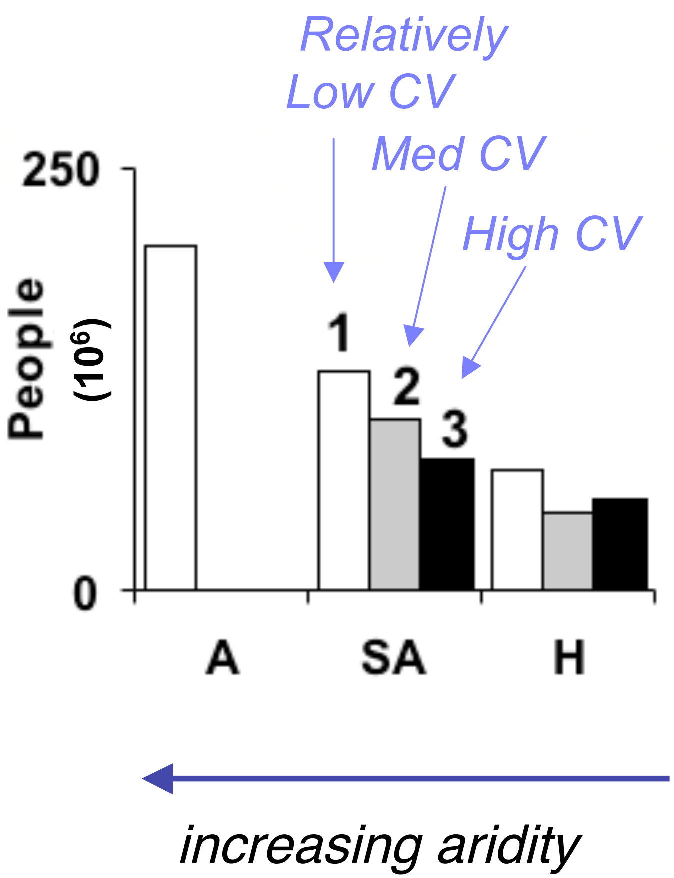
Intra-annual Max:Min Discharge Classes:

- **L** Low (<5)
- **M** Moderate (5 to 50)
- **H** High (>50)

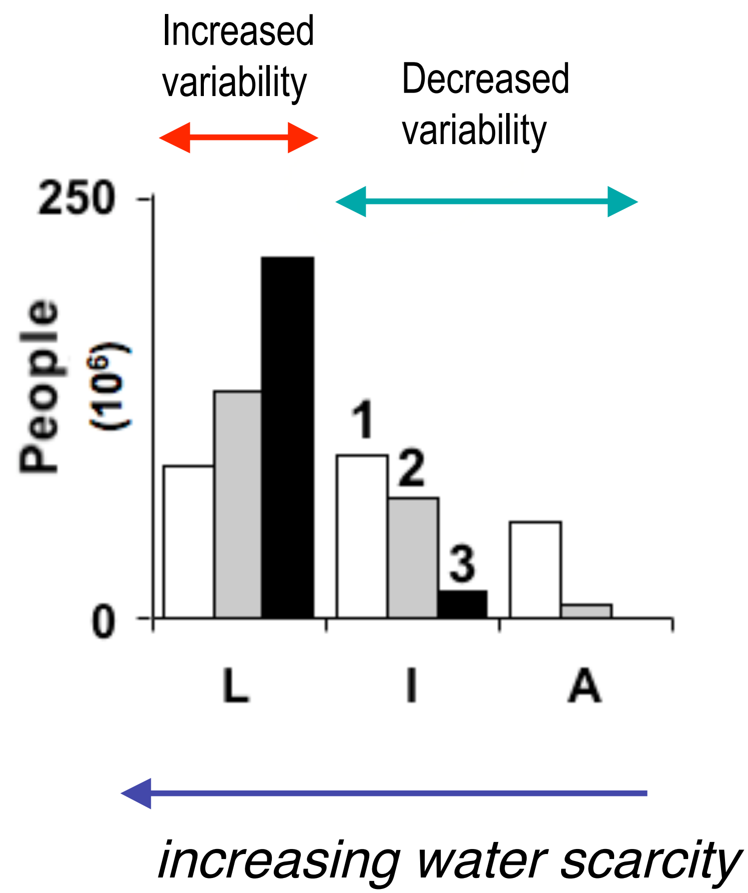
Vörösmarty et al. AMBIO 34: 230-236

Water Resource and Climate Variability Are Different

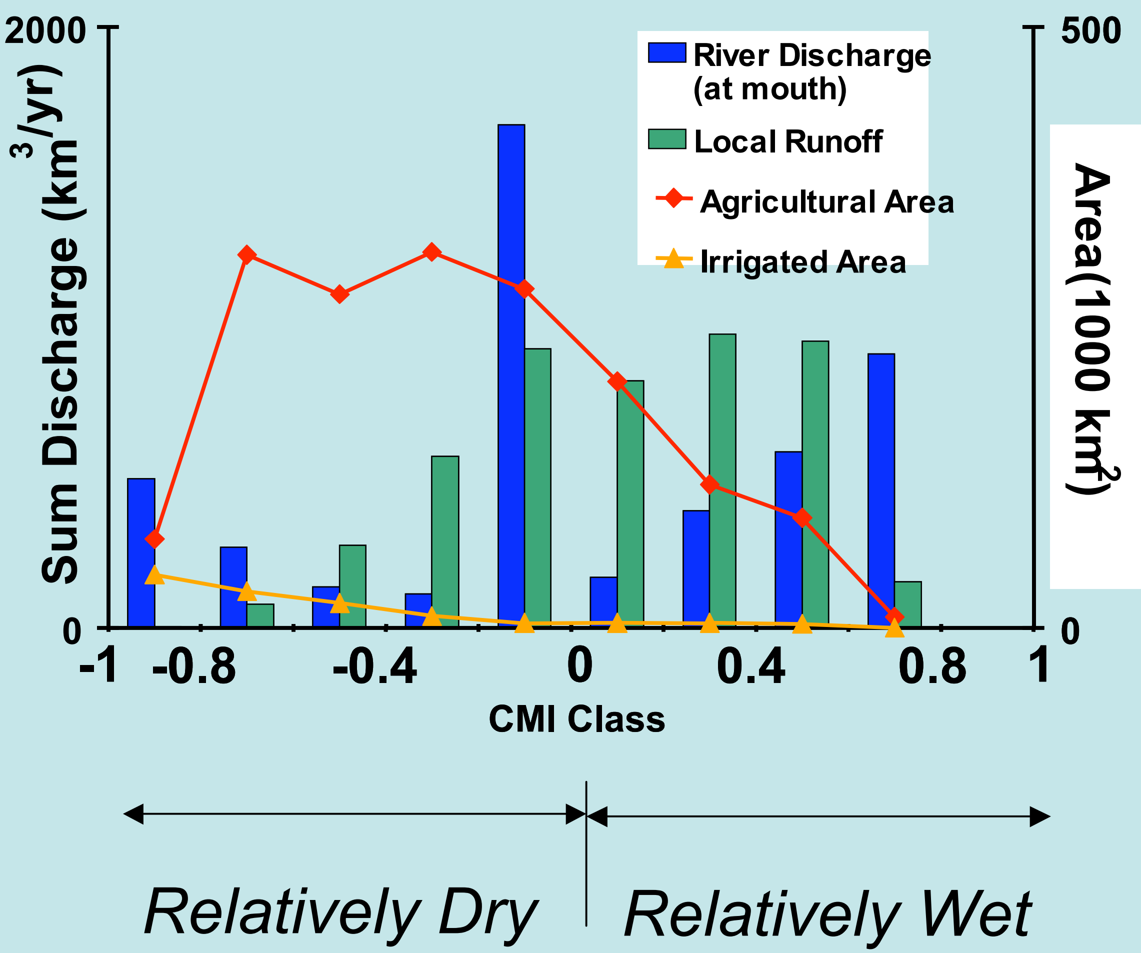
Climate variability (traditional view)



Hydrologic variability through river corridors



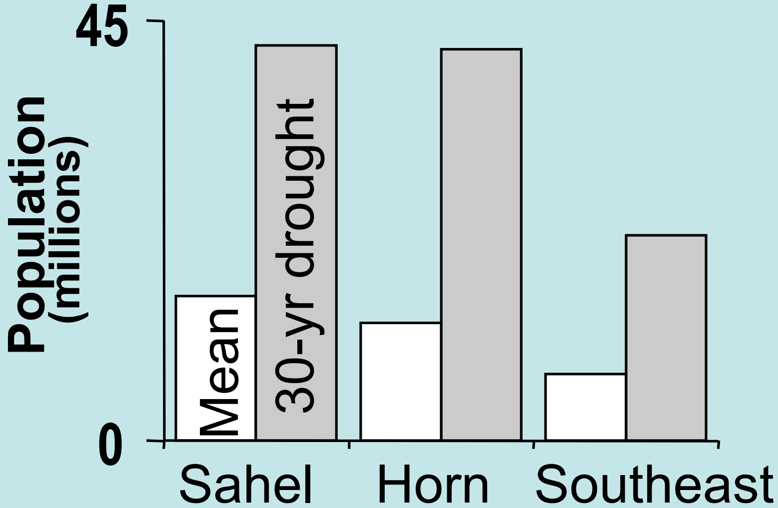
SOME INDICATORS OF AFRICAN FOOD SECURITY

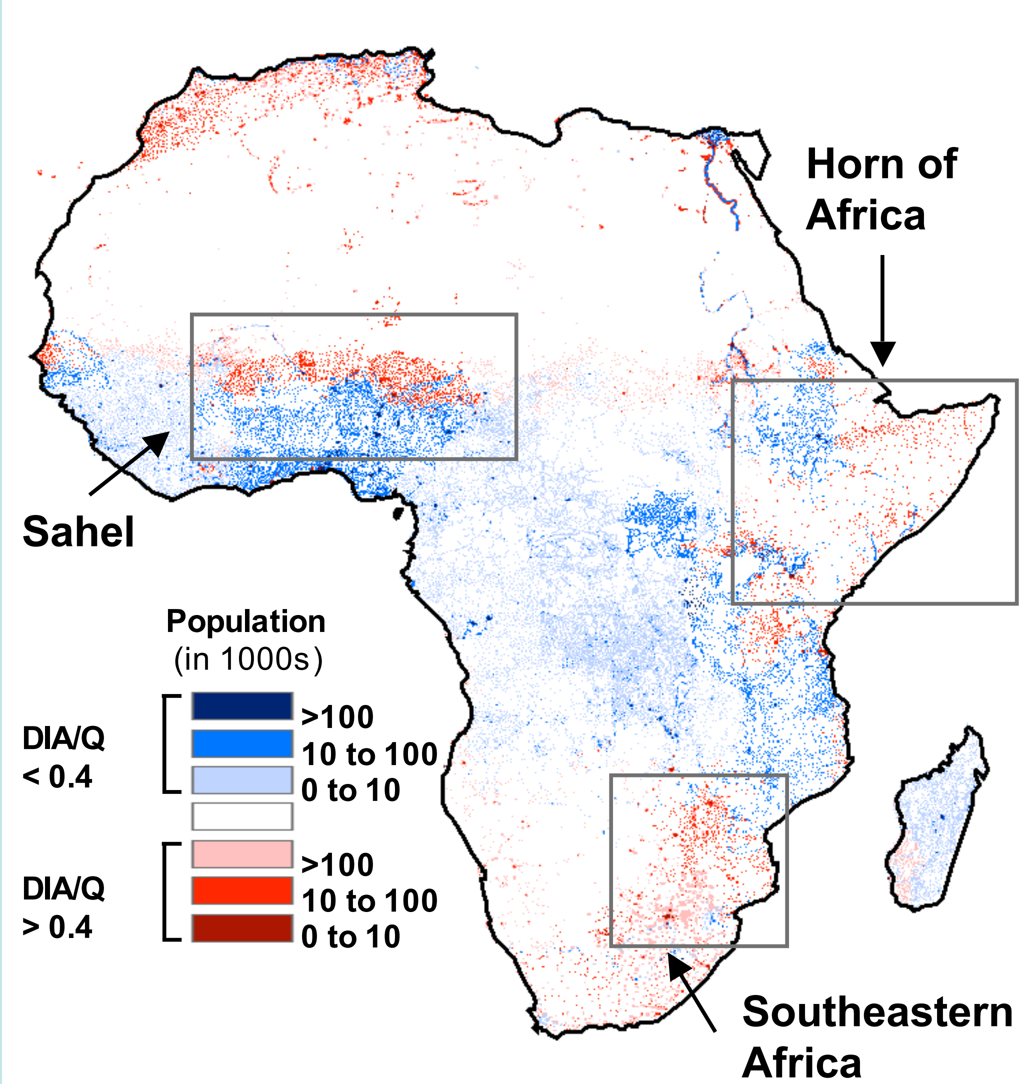


- Agriculture distributed into relatively dry areas
- Much of African cropland unserved by irrigation
- Irrigation water use greatest in driest zones, made possible in part by river corridor flows
- River corridors -- opportunities for water resources but likely to feel impacts of any major “GR2”

Drought Is Key Feature of African Security Issues

Population Above and Below Water Stress Threshold During Drought
-- 30-year duration statistics

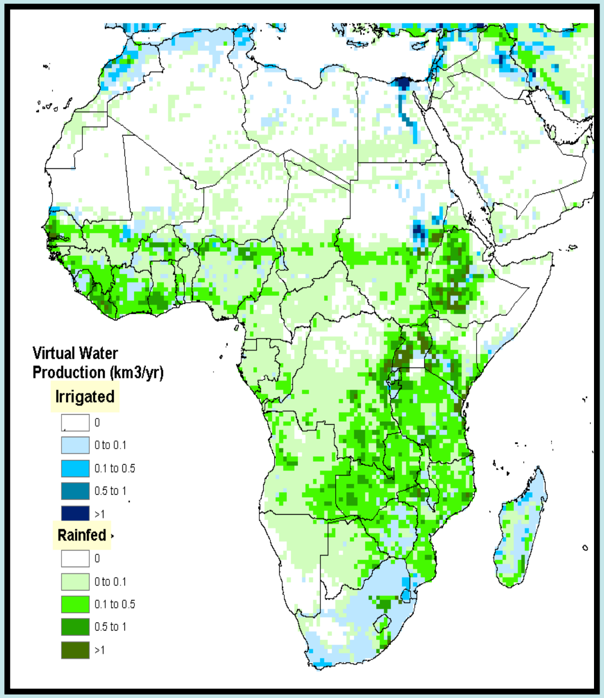




Continental total: Mean --> 25% population w/ stress
30-yr drought --> 40%

Vörösmarty et al. 2005

A NATIONAL WATER ACCOUNT FRAMEWORK



Virtual Water for Africa (km³/yr)

	Crops [1]	Meat [2]	Total
Production	1326	289	1615
Percent of AET [3]	9%	2%	11%
Imports	404	21	425
Exports	50.5	0.3	50.8
VW Balance	1680	309	1989

[1] VW in crops = AET over rainfed cropland +PET over irrigated cropland.
[2] VW in meat = VW in feed/fodder + 30% AET over grazing land.
[3] AET = actual evapotranspiration; percent relative to continental total.

From: Vörösmarty et al. 2005, MA-Water

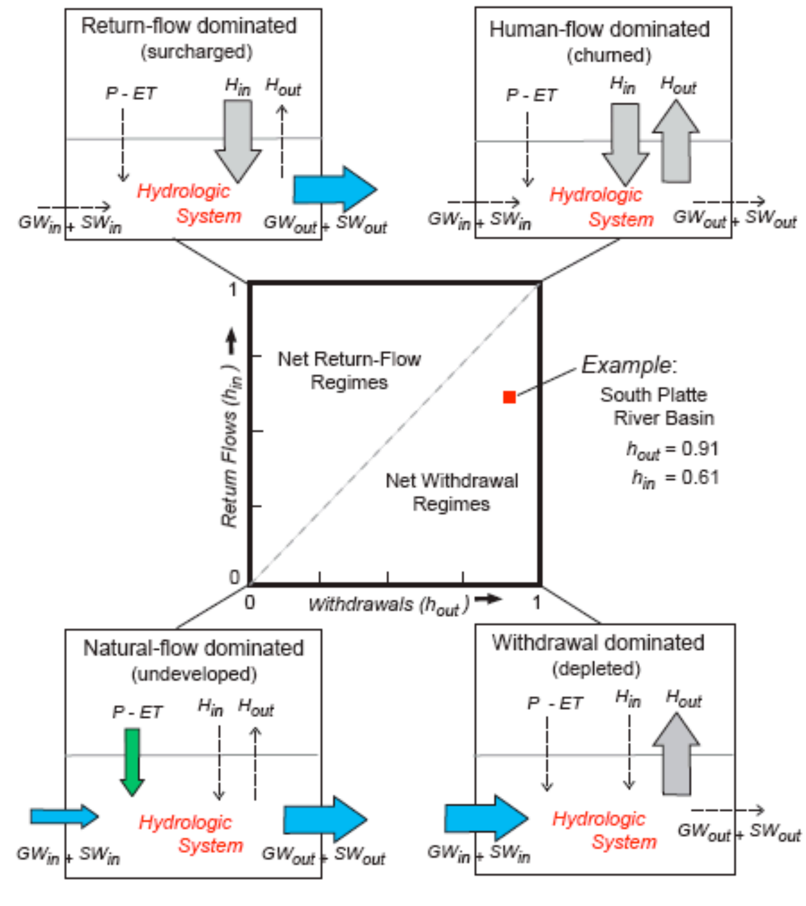


Figure 2. Human water-use regimes. The relative magnitudes of normalized human withdrawals (h_{out}) versus return flows (h_{in}) are plotted on the central plot Example regime is given for South Platte River Basin, U.S., based on *Dennehy et al.* [1993]. The panels show the four end-member regimes that bound the domain of possible water-use regimes for a hydrologic system. Dashed arrows indicate fluxes that are either zero or very small relative to the other fluxes on each panel. For convenience, the natural-flow-dominated panel asumes humid climatic conditions ($P > ET$). See text equations (3), (6), and (7) for definitions of all terms. Fluxes into and out of storage are not shown.

From: Weiskel et al. 2007, WRR

Report…..

By country

--*WWAP Web*

--*Parallel Indicator Docs*

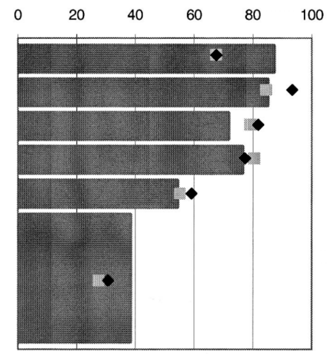
Kenya

SUB-SAHARAN AFRICA
GDP/capita 2004 est. (PPP) $1,100

Income Decile 9 (1=high, 10=low)

Pilot 2006 EPI	
Rank:	93
Score:	56.4
Income Group Avg.	53.2
Geographic Group Avg.	50.5

Policy Categories



	Country	Income Group	Geographic Group
Air Quality	87.0	67.6	67.8
Water Resources	84.8	93.5	84.3
Prod. Nat. Resources	71.4	81.6	78.9
Sustainable Energy	76.5	77.5	80.3
Biodiv. and Habitat	54.1	59.2	54.9
Environmental Health	38.0	30.5	27.7

Indicator Data

		Value	Target	Standardized Proximity to Target (100=target met)
PM10	Urban Particulates (µg/m^3)	44.0	*0*	75.8
OZONE	Regional Ozone (ppb)	15.8	*15*	98.2
NLOAD	Nitrogen Loading (mg/L)	269.4	*1*	94.9
OVRSUB	Water Consumption (%)	13.9	*0*	74.7
OVRFSH	Overfishing (scale 1-7)	6	*1*	16.7
AGSUB	Agricultural Subsidies (%)	0.0	*0*	100.0
HARVEST	Timber Harvest Rate (%)	3.7	*3*	97.4
PWI	Wilderness Protection (%)	16.6	*90*	18.5
PACOV	Ecoregion Protection (scale 0-1, 1=10% each biome protected)	0.7	*1*	69.9
INDOOR	Indoor Air Pollution (%)	85.0	*0*	15.085.0
WATSUP	Drinking Water (%)	62.0	*100*	31.4
ACSAT	Adequate Sanitation (%)	48.0	*100*	36.8
1TO4MORT	Child Mortality (deaths/1000 population 1-4)	13.9	*0*	46.5
ENEFF	Energy Efficiency (Terajoules / million GDP PPP)	4,641.7	*1,650*	87.5
RENPC	Renewable Energy (%)	26.2	*100*	26.2
CO2GDP	CO_2 per GDP (Tonnes / GDP PPP)	258.3	*0*	77.4

From: 2006 PILOT EPI

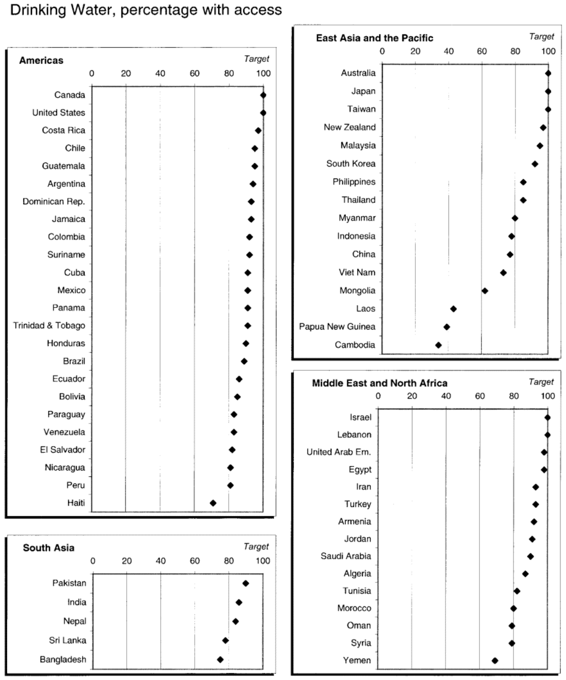
Report…..

Across countries

Proximity-to-Target, by Geographic Peer Group

WATSUP

Drinking Water, percentage with access



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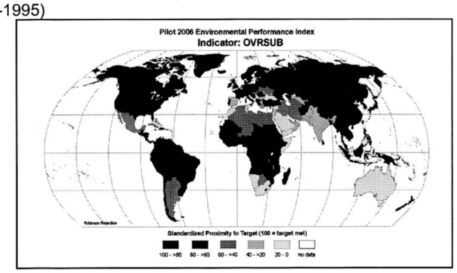
…example-some water components of the EPI (Env. Performance Index)

Indicator: OVRSUB

Policy Category: Water Resources / Biodiversity and Habitat
Description: Water Consumption
Data Source: University of New Hampshire, Water Systems Analysis Group (http://www.watsys.sr.unh.edu), derived using their Water Balance Model, Vörösmarty, C. J., C. A. Federer and A. L. Schloss. 1998. Evaporation functions compared on US watershed: Possible implications for global-scale water balance and terrestrial ecosystem modeling, Journal of Hydrology, 207 (3-4): 147-169.
NOTE: See methodological documentation at the end of this annex for expanded source information.
Time Period: Contemporary (mean annual 1950-1995)
Country Coverage: 171



Target: 0%
Target Source: By definition
QUICK SUMMARY
Maximum: 90.62
Minimum: 0.00
Mean: 13.09
Std Dev: 18.16
Top Performers:
39 countries meet the target for this indicator
Bottom Performers:
Kuwait, Israel, Jordan, Armenia, Somalia

COUNTRY DATA (Units: Percentage of Territory in which Consumption Exceeds 4% of Available Water)

Country	Value	Country	Value	Country	Value
Afghanistan	11.3	Brit. Indian Ocean Terr.	..	Djibouti	23.5
Albania	0.0	British Virgin Islands	..	Dominica	..
Algeria	24.5	Brunei Darussalam	..	Dominican Rep.	20.4
Am. Samoa	..	Bulgaria	36.5	East Timor	0.0
Andorra	..	Burkina Faso	12.2	Ecuador	19.2
Angola	5.5	Burundi	0.0	Egypt	25.5
Anguilla	..	Cambodia	0.0	El Salvador	0.0
Antigua & Barbuda	..	Cameroon	0.0	Equ. Guinea	0.0
Argentina	24.1	Canada	1.7	Eritrea	0.0
Armenia	68.6	Cape Verde	..	Estonia	2.5
Aruba	..	Cayman Islands	..	Ethiopia	18.2
Australia	45.7	Central Afr. Rep.	0.5	Faeroe Islands	0.0
Austria	0.0	Chad	16.4	Falkland Islands	0.0
Azerbaijan	31.4	Chile	16.5	Fiji	0.0
Bahamas	0.0	China	19.6	Finland	0.4
Bahrain	..	Christmas Island	..	France	8.4
Bangladesh	8.8	Cocos Islands	..	French Guiana	0.0
Barbados	..	Colombia	2.8	French Polynesia	..
Belarus	1.8	Comoros	..	Fr. Southern Territories	..
Belgium	49.8	Congo	0.0	Gabon	0.0
Belize	0.0	Cook Islands	..	Gambia	0.0
Benin	0.0	Costa Rica	0.0	Georgia	7.0
Bermuda	..	Côte d'Ivoire	1.8	Germany	15.9
Bhutan	0.0	Croatia	0.0	Ghana	0.0
Bolivia	2.1	Cuba	28.7	Gibraltar	..
Bosnia & Herzegovina	0.0	Cyprus	0.0	Greece	4.4
Botswana	30.6	Czech Rep.	2.6	Greenland	0.0
Bouvet Island	..	Dem. Rep. Congo	0.0	Grenada	..
Brazil	2.3	Denmark	2.3	Guadeloupe	..

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From: 2006 PILOT EPI

Global Scale Initiative Activity:

Indicators & Threats to Freshwater Systems

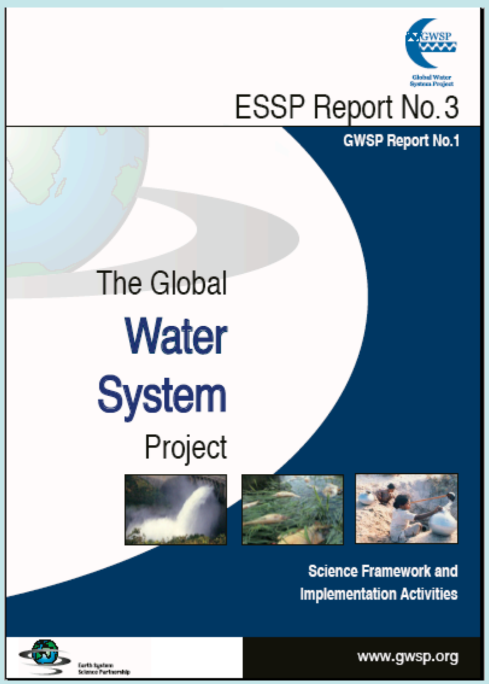
by

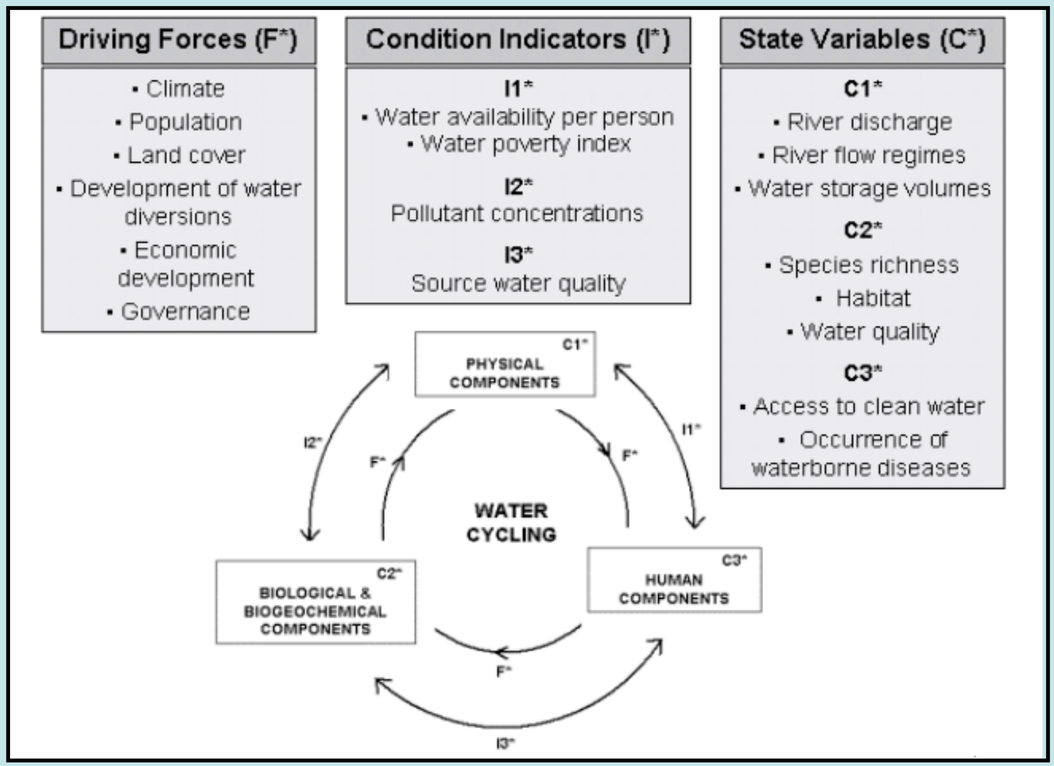
Charles J. Vörösmarty (GWSP co-Chair)

ICTP Water Resources and Developing Countries

3 May 2009 Trieste ITALY

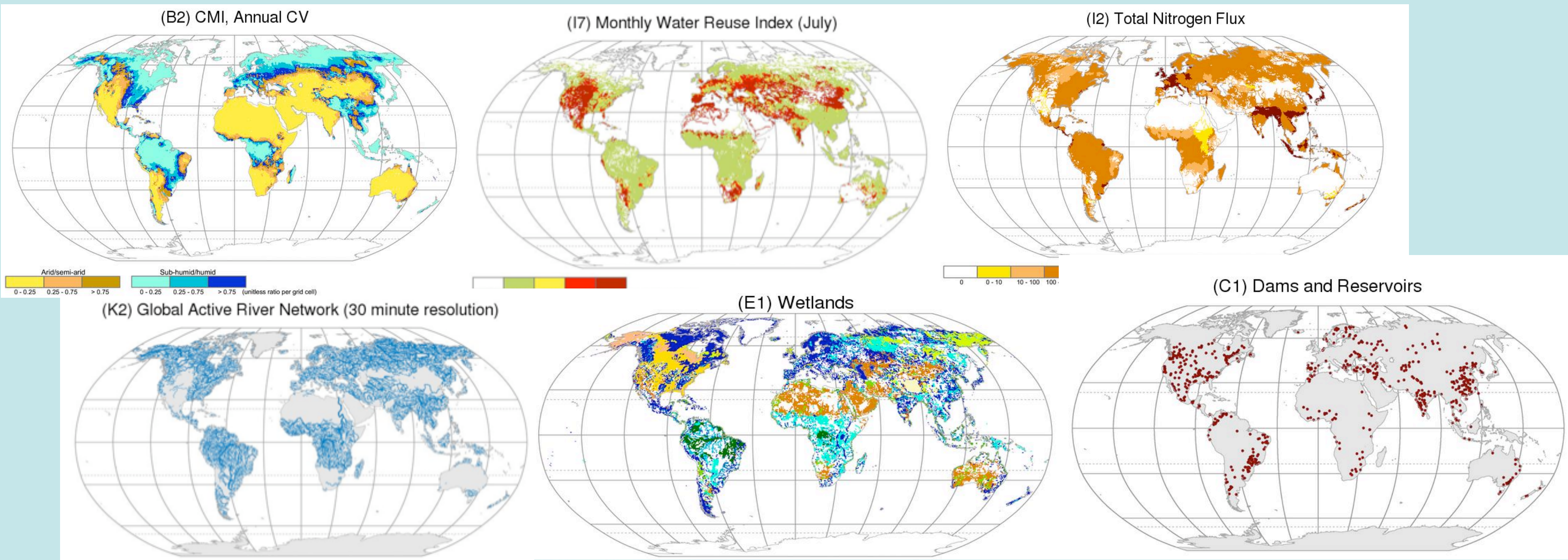
- GOALS of the GWSP Indicators Effort:
  - Develop new class of metrics depicting the GWS, built on geospatial data on geophysics, biology/BGC, socio-economic information
  - Develop information-rich means to engage partners: Inside and outside of GWSP

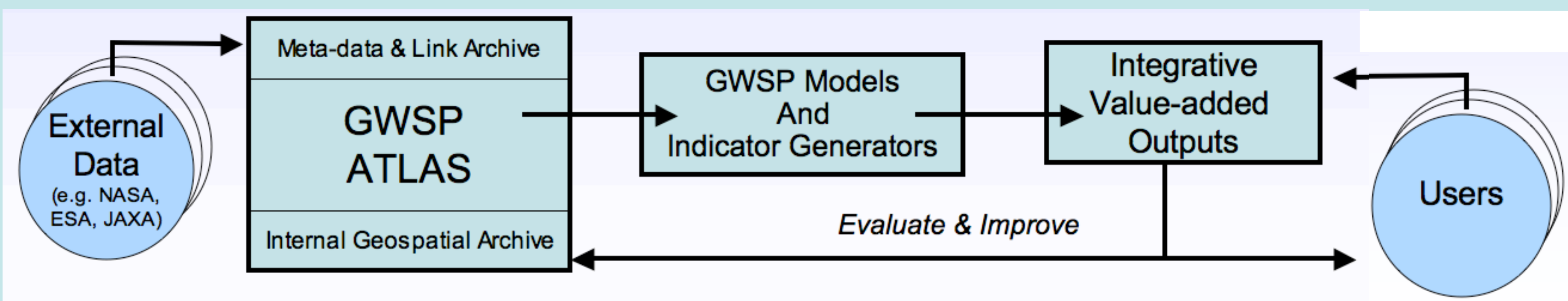


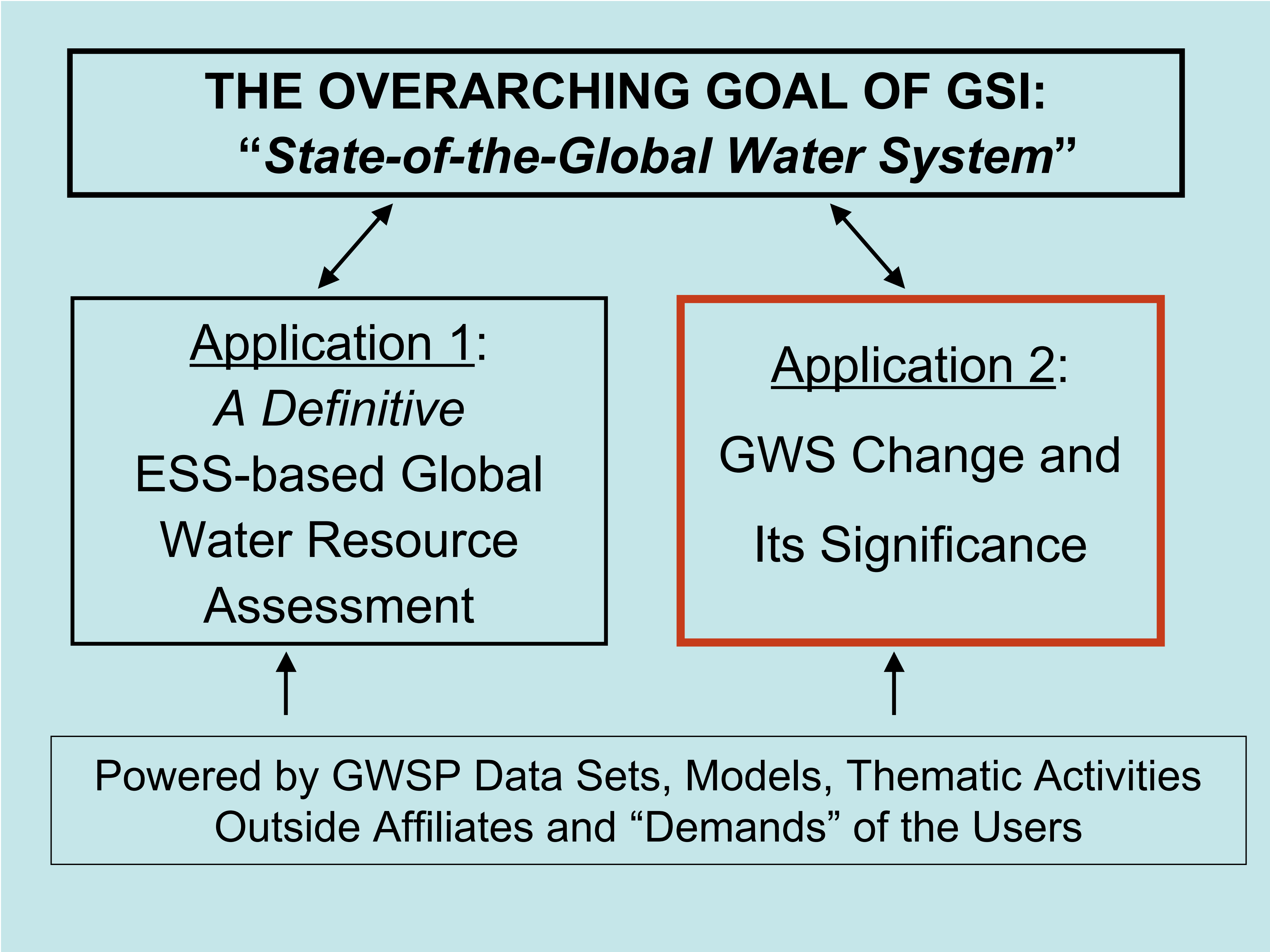


Integrated Approaches to Global Water Resource Assessment and Global Change Studies

Links Geophysics of Water, Governance, Vulnerability, Supply Limitations Imposed by Pollution & Ecosystem Flow Requirements

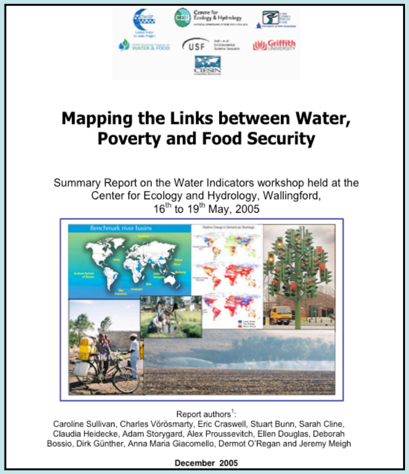





THE OVERARCHING GOAL OF GSI:
"State-of-the-Global Water System"
Application 1:
A Definitive
ESS-based Global
Water Resource
Assessment
Application 2:
GWS Change and
Its Significance
Powered by GWSP Data Sets, Models, Thematic Activities
Outside Affiliates and "Demands" of the Users

Highlights of Recent Progress

- Tasks and supporting activities (from Spring 2005)
  - Hands-on Workshop in Wallingford (Water Wealth/Poverty) (June 2005) 1st *Issues in GWS*
  - Preparatory technical meeting in Durham (EcoHydrology Mapping) (April 2007)
  - Development of tools and data sets
  - TISORL Cross-Cutting Workshop (Theme 4) (Sept. 2007)



Mapping the Links between Water, Poverty and Food Security

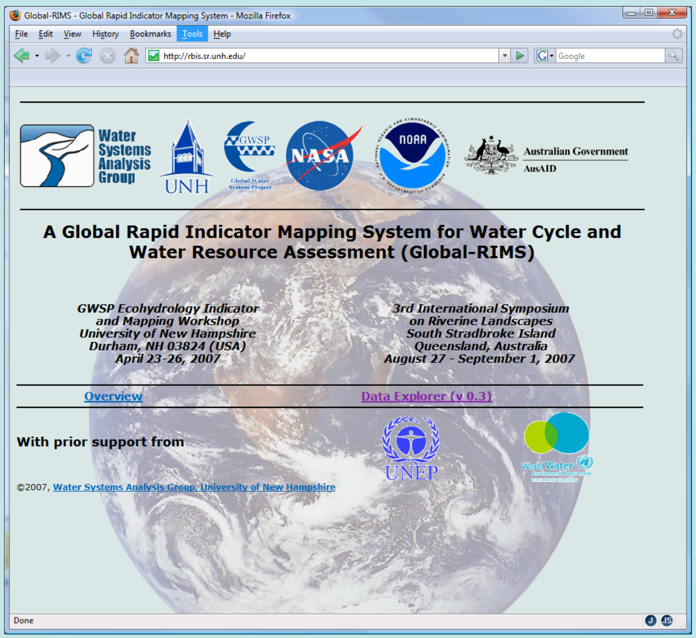
Summary Report on the Water Indicators workshop held at the Center for Ecology and Hydrology, Wallingford, 16th to 19th May, 2005

Report authors[1]:
Caroline Sullivan, Charles Vörösmarty, Eric Craswell, Stuart Bunn, Sarah Cline, Claudia Heidecke, Adam Storygard, Alex Proussevitch, Ellen Douglas, Deborah Bossio, Dirk Günther, Anna Maria Giacomello, Dermot O'Regan and Jeremy Meigh

December 2005

Ecohydrological Mapping Exercise (EME)

Data/Tool Preparation for TISORL: User-defined Data "bundles" (Durham '07)



The key data sets are classified into five broad categories (number of indicators):
1. Flow and Hydrology (11)
2. Hydrologic Connectivity / Floodplains (6)
3. Barriers / Fragmentation (2)
4. Land Use / Watershed Characteristics (5)
5. Biodiversity (after consultation with Diversitas)
Target basins for high resolution prototype tests (with plans for eventual global coverage): Orange (S. Africa), Murray-Darling (Australia), Rio Grande (US, Mexico), Columbia (US), Sao Francisco (Brazil), Mekong (int'l SE Asia), Danube (int'l Europe), Yellow (China), Ganges-Barahmaputra (int'l S. Asia), Volta (int'l W. Africa)

Australian Government AusAID

Oxford University

Griffith UNIVERSITY

UNIVERSITY of NEW HAMPSHIRE

Exploration of EM Indicators: Murray-Darling Test Case

Individual Index*: (X-Xmin) / (Xmax-Xmin)

or I (X-Xmin) / Xmax-Xmin) I

Composite Threat Index * =

([N Potential load]

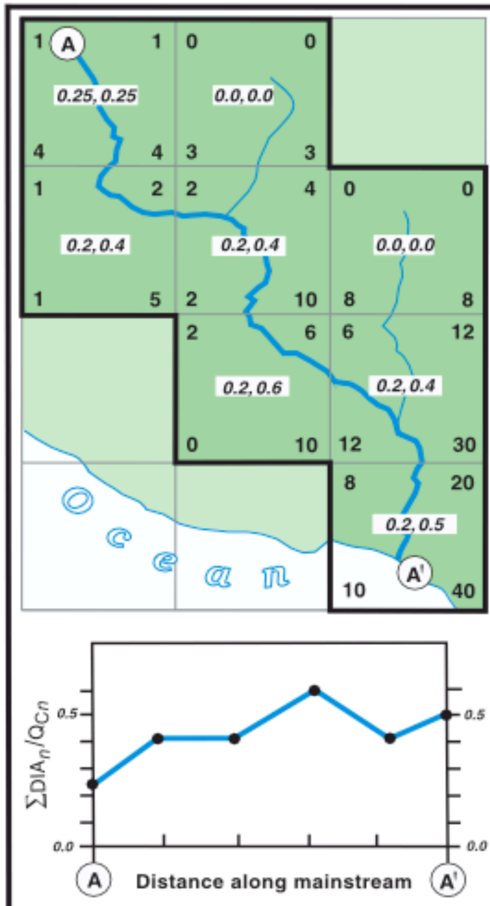
+ [Peak flow timing shift]

+ [Change in Flow Variability]) / 3

Good condition is 0

Highly threatened is 1

* Truncated at 10th, 90th percentile



CALCULATION OF KEY WATER INDICATORS

DIA_n = domestic, industrial, agricultural water use ($km^3\ yr^{-1}$) in cell n

ΣDIA_n = DIA in cell n plus all upstream cells ($km^3\ yr^{-1}$) $= \sum_{i=1}^{n} DIA_i$

R_n = locally-generated runoff (mm/yr)

A_n = area of cell n (km^2)

$QL_n = 10^6 * R_n * A_n$ = locally generated discharge ($km^3\ yr^{-1}$)

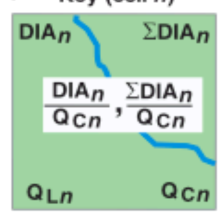
$QC_n = \sum_{i=1}^{n} QL_i$ = river corridor discharge ($km^3\ yr^{-1}$)

DIA_n/QC_n = local relative water use (unitless)

$\Sigma DIA_n/QC_n$ = water reuse index (unitless)

n = position of cell in river network = total number of upstream cells plus cell in question

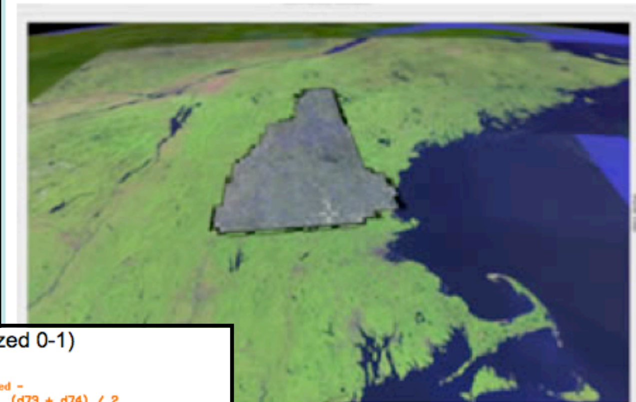
Key (cell n)

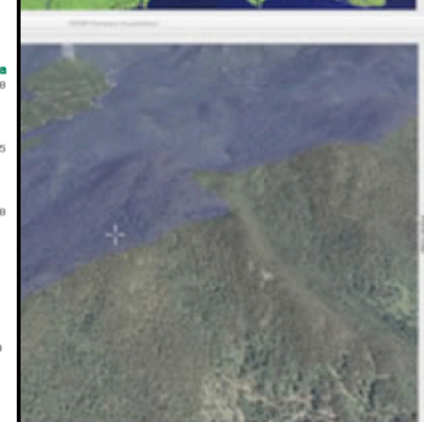


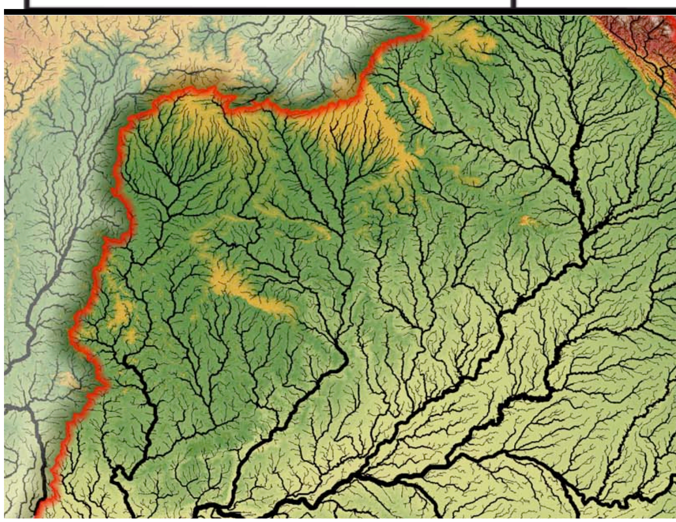
Global RIMS

Global Rapid Indicator Mapping System for Water Cycle & Water Resource Assessment

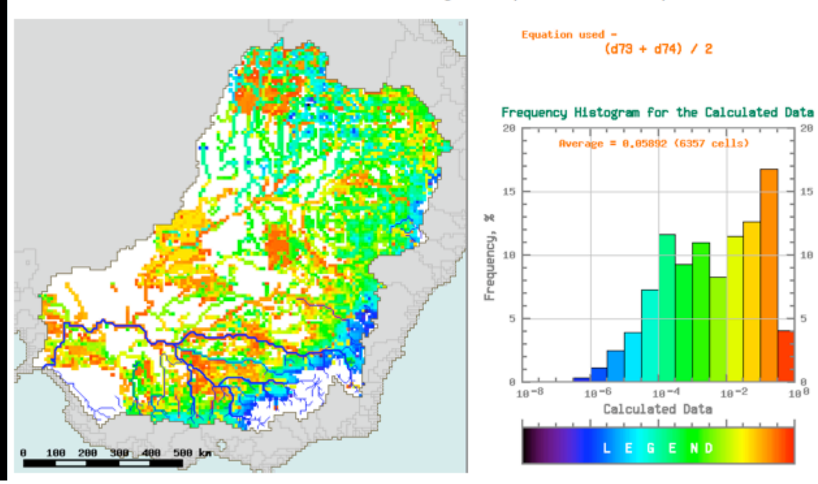
- *DEFINE WATERSHED STATE BASED ON LOCAL AND RECURSIVE INDICES*
- *GOOGLE AND OPEN MAP SERVERS*
- *MAP SYSTEM STATES OVER SPACE & TIME*







Combined Indicator: N Pollution + Timing Shift (normalized 0-1)



…then along comes Halpern & company

www.sciencemag.org SCIENCE VOL 319 15 FEBRUARY 2008

A Global Map of Human Impact on Marine Ecosystems

Benjamin S. Halpern,[1]‡ Shaun Walbridge,[1]* Kim
Fiorenza Micheli,[3] Caterina D'Agrosa,[4]† John F.
Helen E. Fox,[7] Rod Fujita,[8] Dennis Heinemann,[9] H
Matthew T. Perry,[1] Elizabeth R. Selig,[6,12] Mark S

The management and conservation of the world's o
distribution and intensity of human activities and t
ecosystems. We developed an ecosystem-specific, m
data sets of anthropogenic drivers of ecological cha
indicates that no area is unaffected by human influe
affected by multiple drivers. However, large areas c
particularly near the poles. The analytical process a
regional and global efforts to allocate conservation
management; and to inform marine spatial plannin

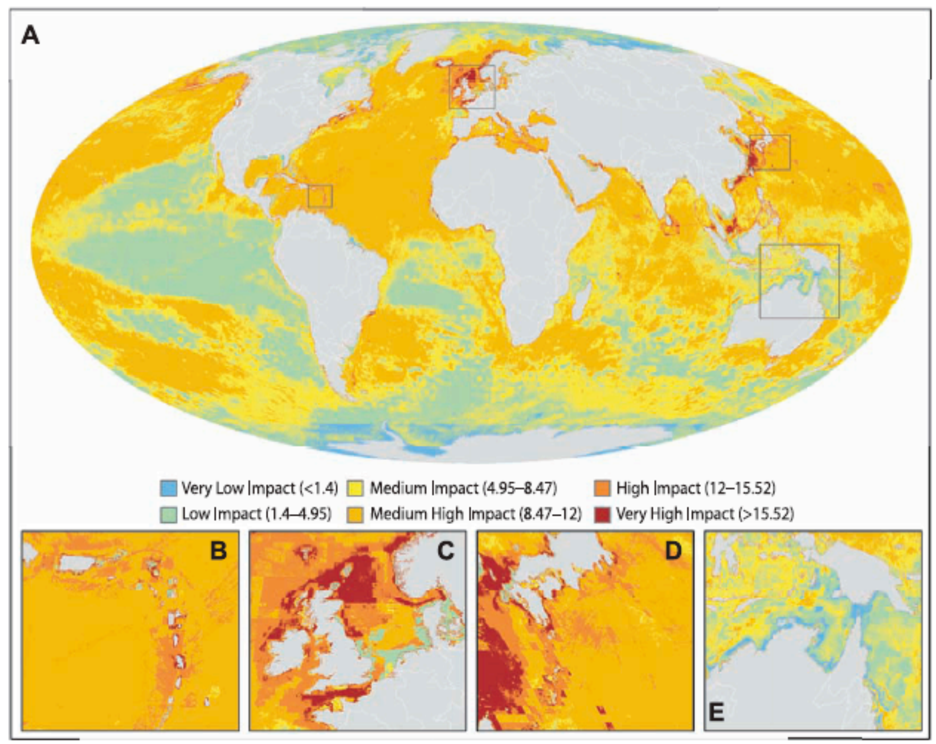


Fig. 1. Global map (**A**) of cumulative human impact across 20 ocean ecosystem types. (Insets) Highly impacted regions in the Eastern Caribbean (**B**), the North Sea (**C**), and the Japanese waters (**D**) and one of the least impacted regions, in northern Australia and the Torres Strait (**E**).

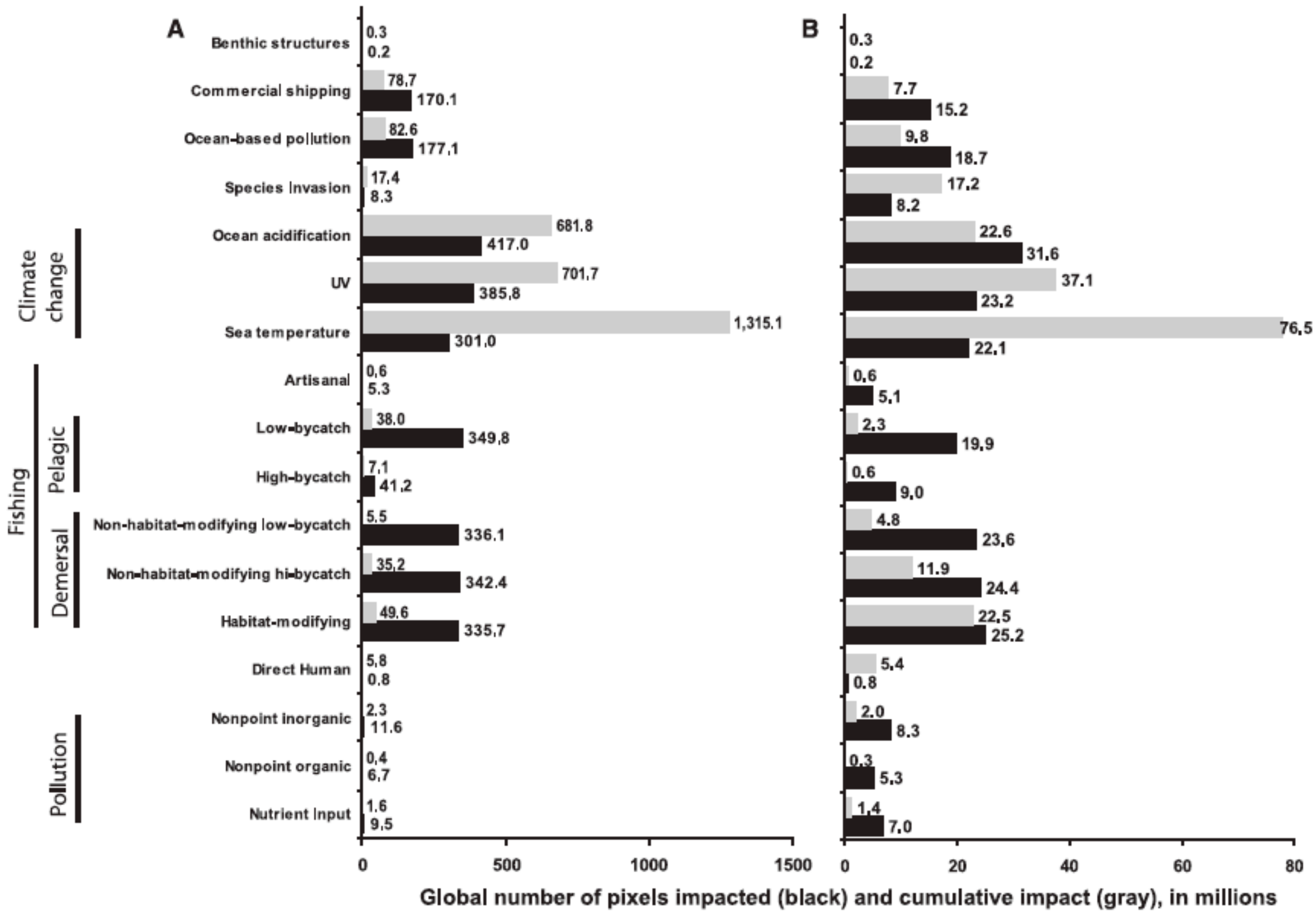


Fig. 4. Total area affected (square kilometers, gray bars) and summed threat scores (rescaled units, black bars) for each anthropogenic driver (**A**) globally and (**B**) for all coastal regions <200 m in depth. Values for each bar are reported in millions.

FW Response to Halpern et al

**Discussions fueled by beer, wine,
and caffeinated beverages**

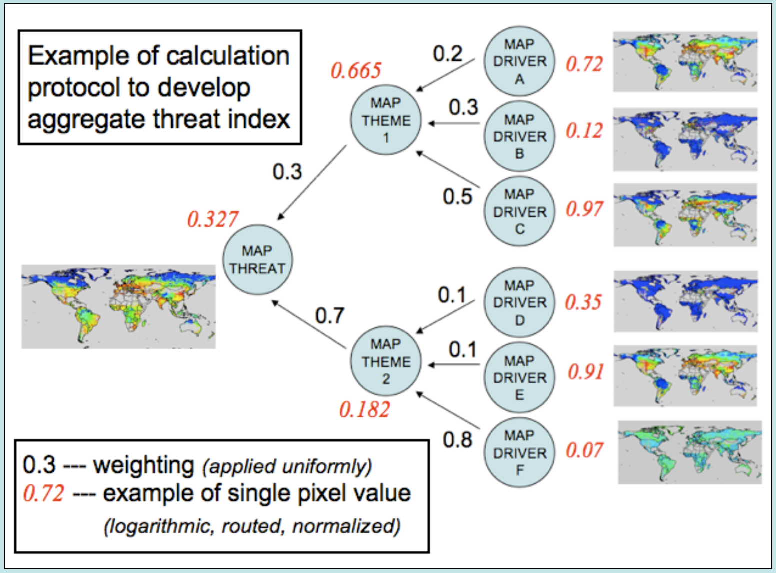
GOAL: *To convene, execute, and synthesize the outcomes from a joint GWSP-DIVERSITAS Workshop on Global Threats to Freshwater, resulting in a strategic paper to* Science *that will serve as the freshwater analogue or complement to the Halpern et al. (2008) contribution on human threats to the world's oceans.*

Through….

two primary maps presented in the paper, which are effectively two geographies of:

1. Global threats to the freshwater resource base for human use, which would necessarily consider water for the domestic, industrial, and agricultural sectors; and,
2. Global threats to freshwater required and made available to natural ecosystems

…focus on "well-reasoned" threats



Calculation Strategy

- Conjoin classes of threat through consensus-based weightings (0-1)

$$T^k = \sum_{j=1}^{5} \sum_{i=1}^{N_j} W_j^k \omega_{j,i}^k D_i^k$$

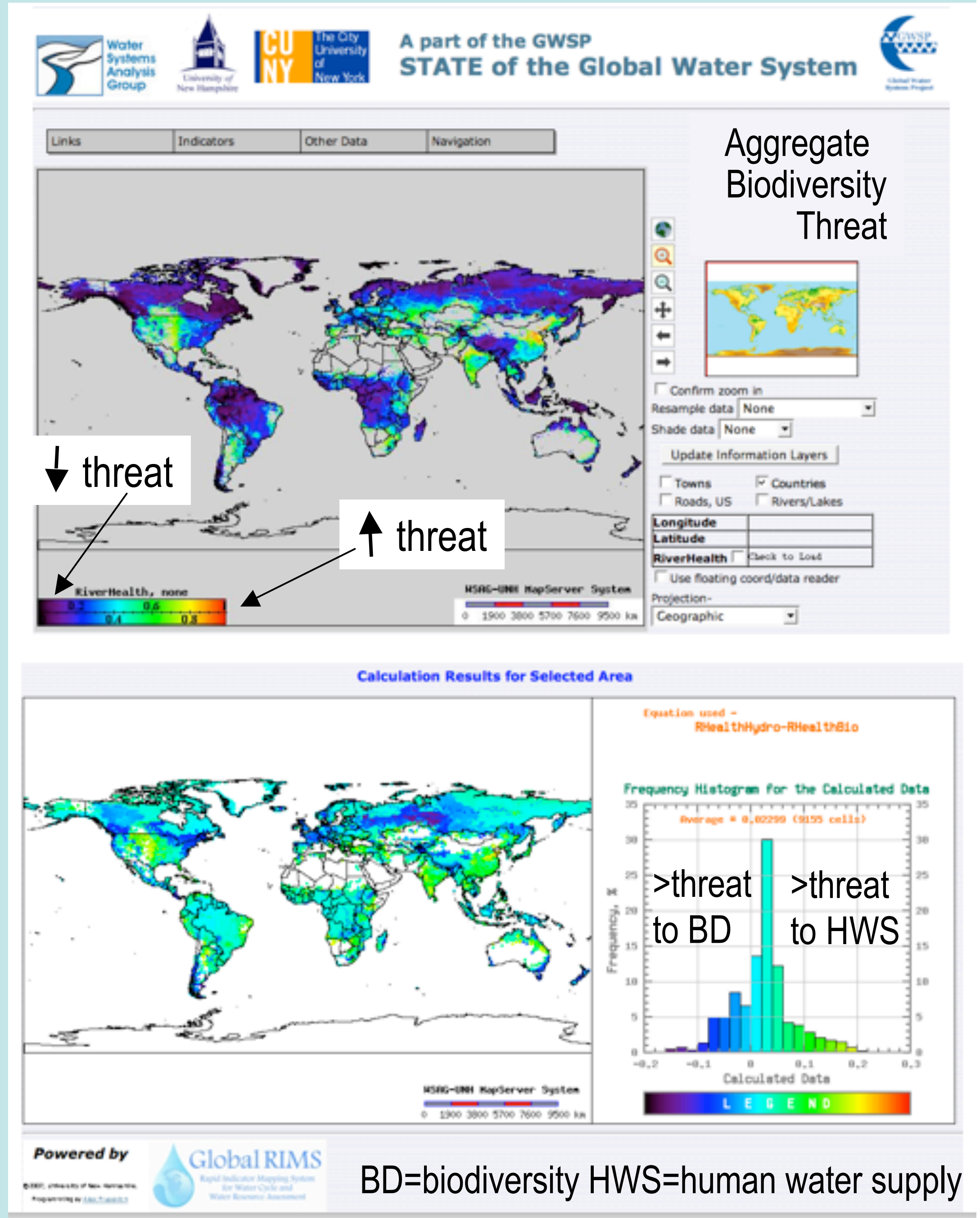
- "Themes" and within-theme "drivers"
- Threat routed through networks, normalized

Driver Weights Table

Theme Name	Theme Weight: Human water security	Theme Weight: BioDiversity	Driver #	Driver Name	Within Theme Driver Weight: Human water security	Within Theme Driver Weight: BioDiversity	Effective Driver Weight: Human water security	Effective Driver Weight: BioDiversity
Surrounding Watershed Disturbance	0.20	0.19	1	Converted Agricultural Land	0.31	0.28	0.0620	0.0532
			2	Imperviousness	0.20	0.25	0.0400	0.0475
			3	Livestock Density	0.26	0.25	0.0520	0.0475
			4	Soil Salinization	0.23	0.22	0.0460	0.0418
				Theme Total	1.00	1.00		
Pollutants	0.32	0.24	5	Nitrogen Loads	0.18	0.15	0.0576	0.0360
			6	Phosphorus Loads	0.11	0.14	0.0352	0.0336
			7	Mercury	0.30	0.00	0.0960	0.0000
			8	Pesticides	0.22	0.14	0.0704	0.0336
			9	Water Erosion	0.03	0.18	0.0096	0.0432
			10	Organic Loads (BOD)	0.12	0.19	0.0384	0.0456
			11	Potential Acidification	0.04	0.11	0.0128	0.0264
			12	Thermoelectric Cooling	0.00	0.09	0.0000	0.0216
				Theme Total	1.00	1.00		
Aquatic Habitat Fragmentation	0.11	0.23	13	Dam Density	0.81	0.65	0.0891	0.1495
			14	Floodplain Connectivity	0.19	0.35	0.0209	0.0805
				Theme Total	1.00	1.00		
Flow Distortion	0.36	0.23	15	Relative Loss of Discharge	0.47	0.26	0.1692	0.0598
			16	Discharge Coefficient of Variability	0.15	0.12	0.0540	0.0276
			17	Timing Shift of Maximum Flow	0.04	0.13	0.0144	0.0299
			18	Change of Flow Range	0.09	0.12	0.0324	0.0276
			19	Change of Frequency of Zero Flow	0.07	0.19	0.0252	0.0437
			20	Relative Water Withdrawal vs. Supply	0.10	0.10	0.0360	0.0230
			21	Residency Time Change Downstream from Dams	0.08	0.08	0.0288	0.0184
				Theme Total	1.00	1.00		
Biotic Threads	0.01	0.11	22	Invasive Fish Species	0.50	0.36	0.0050	0.0396
			23	Catch Pressure	0.50	0.64	0.0050	0.0704
All Themes Total	1.00	1.00		Theme Total	1.00	1.00	1.00	1.00

GWSP-DIVERSITAS PARTNERSHIP

- Consensus-based effort
- Map & assess threats to
  -Human water supply
  -Aquatic biodiversity
- >20 global, geospatial data sets on 5 theme areas *(watershed disturbance, pollutants, habitat fragmentation, flow distortion, invasive species)*



With that introduction….
….the lab will continue with some hands-on experiments with the Global-RIMS toolkit and some demonstration data sets

Global RIMS

Global Rapid Indicator Mapping System for Water Cycle & Water Resource Assessment

See: http://riverhealth.sr.unh.edu/

This is a work-in-progress….

….and the lab exercise was prepared as a service to you, for instructional purposes only

….as a professional courtesy <u>please **do not** cite cite or redistribute any data sets or indicators</u>

Global RIMS

Global Rapid Indicator Mapping System for Water Cycle & Water Resource Assessment

See: http://riverhealth.sr.unh.edu/

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