Report Card BMI: Indicators, thresholds, weightings and normalisations

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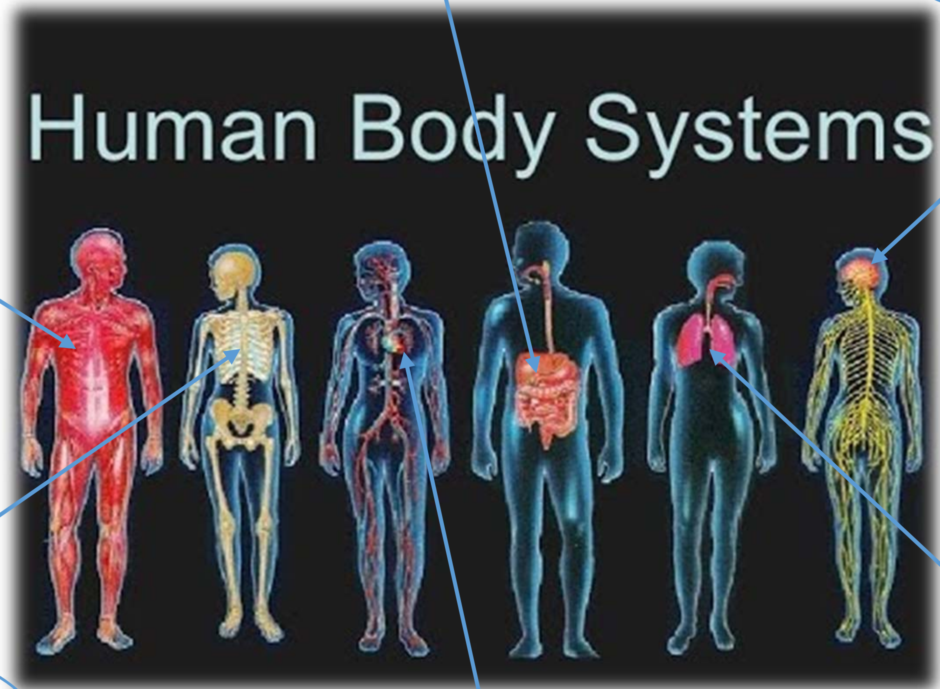
The maths and science behind report cards

What if your report card was a person?

Automations and macros

Command centre: metrics, scores, grades

Human and financial resources



Indicators

End users and the community

Monitoring data

Overview

1. Objectives
2. Framework
3. Indicator selection
4. Indexing method (thresholds/benchmarks)
5. Scoring method
6. Weighting / combination
7. Grades
8. Report card!

But first, a game!

Activity 1: Who owns this formula?

Equation 1:

$$\text{Score} = 100 \times \left(1.0 - \left|\frac{(x - \text{Benchmark})}{(\text{WCS} - \text{Benchmark})}\right|\right)$$

Where: x = sample result for the indicator
Benchmark = water quality objective or guideline
WCS = worst case scenario

Equation 2 $$WQI = \frac{10}{4n}\sum_{i=1}^{n} I_i - 0.5$$

Equation

$$V = \frac{(z_0 - M_1)T_1 + (M_1 - M_2)T_2 + (M_2 - M_3)T_3 + (M_3 - M_4)T_4 + (M_4 - z_1)T_5}{D}$$

Indicators

- Environmental/ecological indicators
- “Human” indicators – social, cultural, economic, stewardship, etc
- Point in time vs. cumulative indicators (indicator species; ecosystem-level indicators; indicators of resilience and change)
- Wide variety of possible indicators – which to select? Depends on:
  - Local drivers/pressures
  - What can be accurately measured (DO)
  - Whether we know what’s “good” and “bad”
  - What r
  - What’s

Fitzroy Basin

- Environmental indicators only
- Started with over 100 potential indicators, narrowed down using pre-defined selection criteria:

Source: Flint et al., 2017

Table 1
Predefined selection criteria (SC) used to assess potential indicators for inclusion in the Ecosystem Health Index for the Fitzroy Basin.

Data:	
SC1.	Reliable data currently available for the Fitzroy Basin[a]
SC2.	Suitable interpretative algorithms are available
SC3.	Errors, reliability and uncertainty in measurement are known and acceptable[a]
SC4.	Temporal and spatial variability can be accounted for
Interpretation and communication	
SC5.	Guidelines/ objectives are in place and relevant to the region[a]
SC6.	Used in other monitoring programs (consistent with other regions, states, nations)
SC7.	Scientific interpretation is straightforward and meaningful
SC8.	Simple to communicate and good public understanding
Relevance:	
SC19.	Important to ecosystem function (will exposure cause serious environmental effects?)
SC10.	Sensitive to changes in ecosystem function
SC11.	Contributes to assessment of ecosystem resilience
SC12.	Related to regional, state, national, international policies and management goals
Practicality and timeliness:	
SC13.	Feasibility and logistics to measure (monitor and analyse) are consistent with outcome benefits
SC14.	Time requirements to measure (monitor and analyse) are consistent with outcome benefits
SC15.	Costs to measure (monitor and analyse) are consistent with outcome benefits
SC16.	Provides an early warning of ecosystem health decline

[a] Critical criteria – low score means automatic disqualification of a potential indicator from the index.

Indicator “categories”

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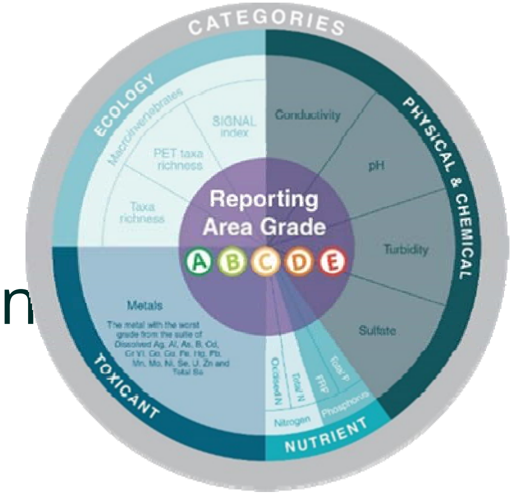
- Why use categories?
  - Simplify the list
  - Allow for different weightings
  - But they add another ‘layer’ of averagin
  - May not always be necessary
    - Anyone not use indicator categories?



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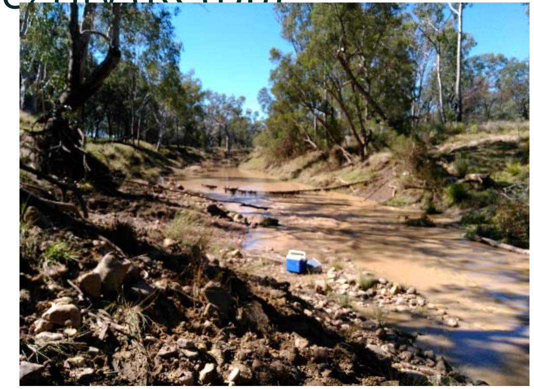
Thresholds

- Development will depend on scoring methodology being used
- Fitzroy Basin method uses two thresholds
  - Reference threshold or 'Benchmarks' as the best possible condition
  - Value above or below which ecosystem is compromised 'Worst case scenario (WCS)'
- Set using:
  - Conditions at reference sites
  - Existing water quality guidelines (e.g. ANZECC, Qld WQOs
  - Modelled values
  - Professional best judgement
  - Combination of the above
- Reference conditions can be a problem! Stoddard et al (2006)
  - Natural conditions; reference condition for biological integrity (RC(BI))
  - **Minimally disturbed condition (MDC)**
  - Historic condition (HC)
  - Least disturbed condition (LDC) ("best available")
  - Best attainable condition (BAC)
  - Expert opinion
- What do you use?



Complexities in threshold setting

- Can be difficult to represent all waterway types and conditions that naturally occur in a large catchment
- E.g. Fitzroy thresholds
  - Water Quality Objectives
    - only been established for low flow (ambient) conditions, except for EC, but most of our data are from high flow conditions – so we had to adjust for this
    - do not account for the influence of other factors that might influence ambient parameters across seasons and years, such as variations in climatic factors or ground water flow
  - Default ANZECC guidelines may not be local
    - E.g. high background levels of some metals, but r issues, so how much is bioavailable and are local relatively tolerant?

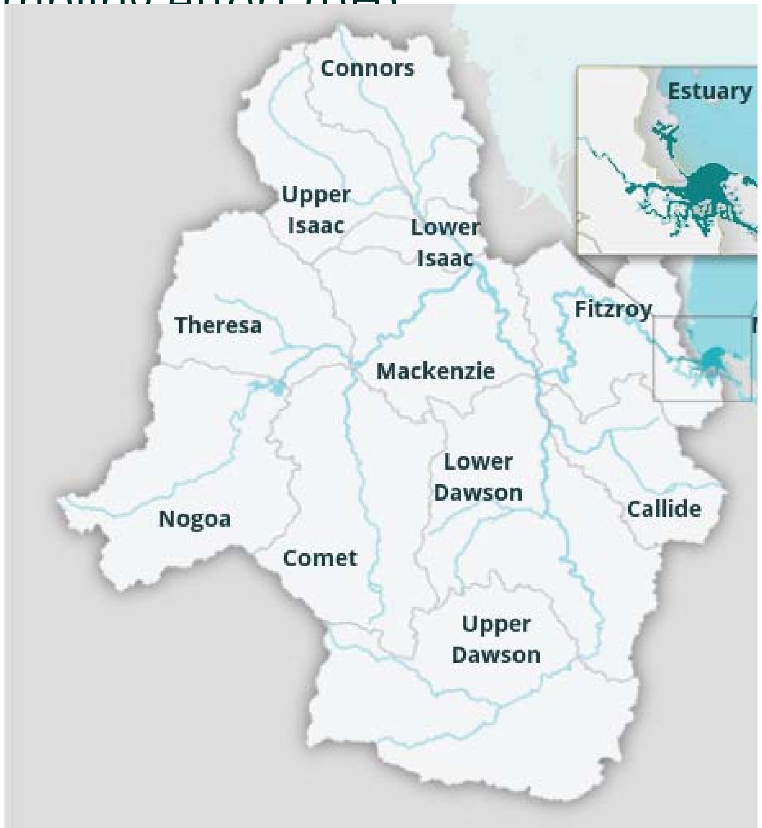
The importance of scale

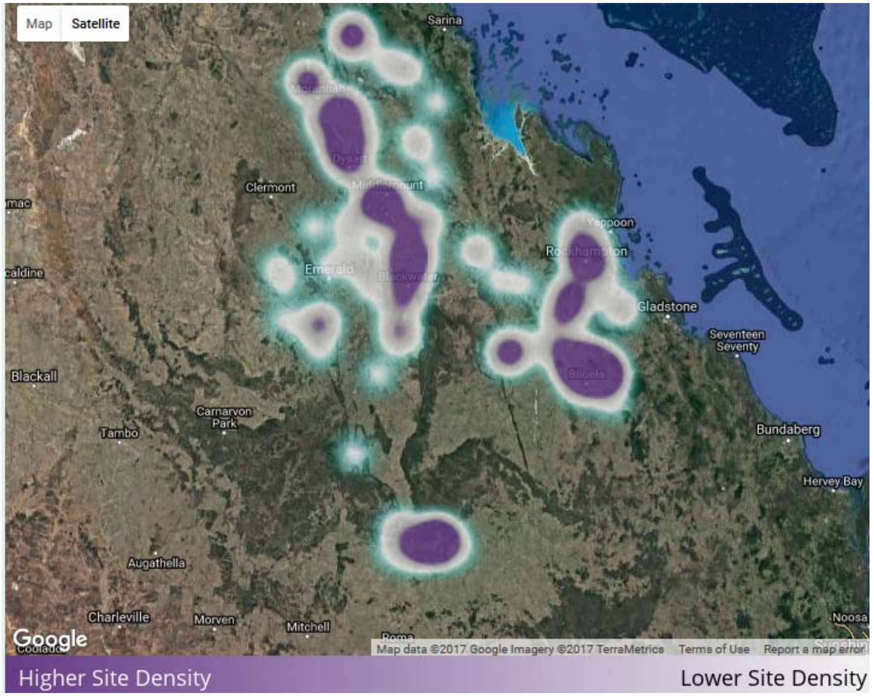
Spatial scale

Where to sample (splitting into smaller “regions”

to address some variability)

Spatial variation in sampling effort (pH)





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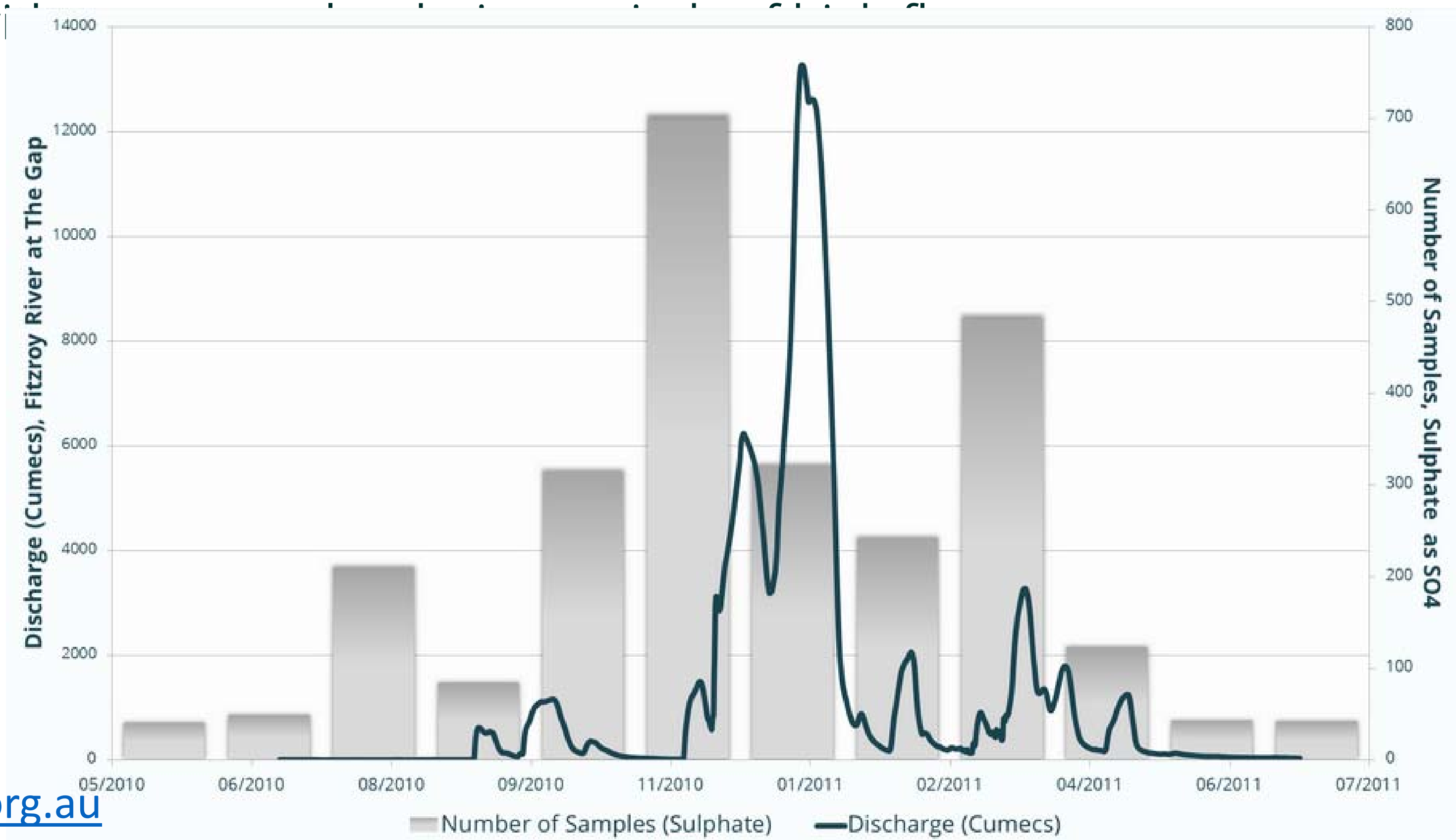
The importance of scale

Temporal scale

- Data are not collected evenly through the year. e.g. sulfate samples across the Fitzroy Basin compared to the hydrograph throughout the year at the end of the Fitzroy River. Considerable variation in sampling effort over the year wi



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Ooh! It's game time again.

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Activity 2: "Average Joe/Jo test"

Step 1: Look in your program design / technical report. Find the bit that says what you've done with your data to get a score.

Step 2: Read that bit.

Step 3: Can you understand exactly what's been done? (Note: it's okay if you don't!)

Step 4: Do you think your Nan and Pop would understand what's been done? Your Mum and Dad? How about your 17 year old neighbour? Does this matter: who is your audience?

Scoring

$$\text{Score} = 100 \times \left(1.0 - \left|\frac{(x - \text{Benchmark})}{(\text{WCS} - \text{Benchmark})}\right|\right)$$

Where: x = sample result for the indicator
Benchmark = water quality objective or guideline
WCS = worst case scenario

- Once indicators are selected, need to work out how to score them.
- Approach for Fitzroy Basin was developed through reviewing a variety of international programs and adapted the SEQ Healthy Waterways method.
  - Evaluates an observed value against and upper and lower "expected" value (Bunn et al., 2010).
  - Score given to the observed value then relates to its position against the expected range.
  - Each individual score provides an evaluation of performance.
  - Appropriate to drill down through an ecosystem health index to individual scores.
- Normalisation to allow combination and

Weighting/averaging

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- Okay, great! I've got heaps of scores. Now what?
- Combination approaches
  - Median / mean / worst score / others?
  - Apply weightings
  - Ready to roll up (next!)

- What impacts on your decisions?
  - Level of complexity
  - Level of understanding of the system
  - Data availability
  - Relative importance of the indicators…

Relative importance of indicators

- Giving more weight to environmental impacts
  - Fitzroy Basin scores toxicants (metals/metalloids) using the “worst score” across the toxicant indicators
  - What else might this apply to? Pesticides? Cyanide? BTEX?
  - Which indicators are your MOST IMPORTANT indicators?

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Grading breakpoints

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- Grading image (e.g. "A to E" style, but there are others)

- What's the difference between 32.9 and 33.1?

  For the Fitzroy Basin, it's the difference between a D and a C.

- But why should that difference be so much more important than the difference between 32.8 and 32.9?

Score (%)	100	67<B<99	33<C<67	0<D<33	0
Grade	A	B	C	D	E

- Putting up with some contrived/artefactual results to the benefit of communication

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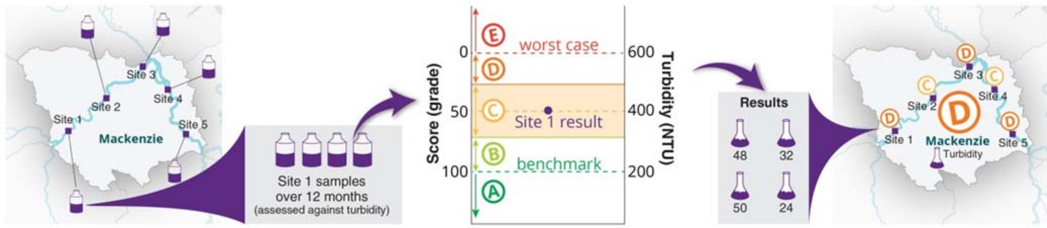
Rolling it up

From site to catchme



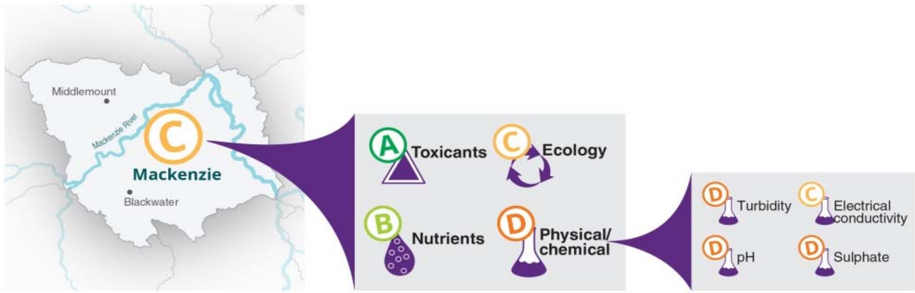
Each reporting area contains numerous sites where samples are collected throughout the year.

All results from these samples (collected at each site) are scored against each indicator.

These scores are averaged by comparing the result to defined thresholds in healthy and unhealthy ecosystems.

Sample scores for each indicator are then averaged to determine an overall grade for each indicator for each site.

These grades are then averaged to determine an overall grade for each indicator for each reporting area.



An overall grade for each reporting area is determined by averaging the overall grades for each of the four ecosystem health categories.

The category grades are determined by averaging the overall grades for the indicators within each category.

Grades for each indicator are awarded by averaging scores for each site that falls within that reporting area.

Indicatory to category to catchment

Catchments to Basin

Grades for all 13 reporting areas (which are comprised of 11 catchments as well as Estuary and Marine) are averaged to determine an overall grade for the Fotzroy Basin.

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Game on.

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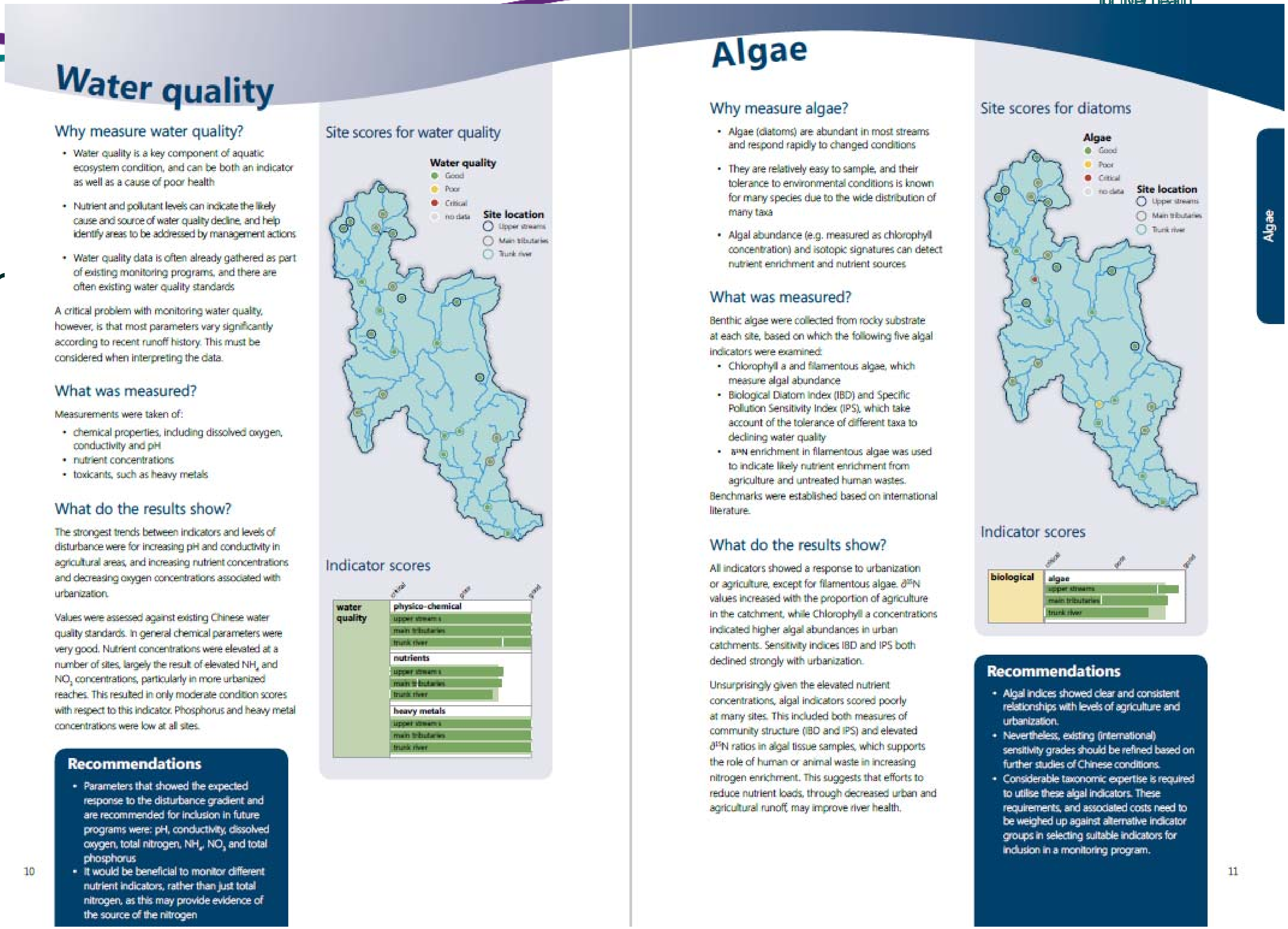
Despite variety across reports, what's the one thing we all have?

Activity 3: Indicator Bingo!

Putting things together. Some examples…

Gui River Report Card, China (IWC) 2009



Water quality

Why measure water quality?

- Water quality is a key component of aquatic ecosystem condition, and can be both an indicator as well as a cause of poor health
- Nutrient and pollutant levels can indicate the likely cause and source of water quality decline, and help identify areas to be addressed by management actions
- Water quality data is often already gathered as part of existing monitoring programs, and there are often existing water quality standards

A critical problem with monitoring water quality, however, is that most parameters vary significantly according to recent runoff history. This must be considered when interpreting the data.

What was measured?

Measurements were taken of:

- chemical properties, including dissolved oxygen, conductivity and pH
- nutrient concentrations
- toxicants, such as heavy metals

What do the results show?

The strongest trends between indicators and levels of disturbance were for increasing pH and conductivity in agricultural areas, and increasing nutrient concentrations and decreasing oxygen concentrations associated with urbanization.

Values were assessed against existing Chinese water quality standards. In general chemical parameters were very good. Nutrient concentrations were elevated at a number of sites, largely the result of elevated NH_4 and NO_3 concentrations, particularly in more urbanized reaches. This resulted in only moderate condition scores with respect to this indicator. Phosphorus and heavy metal concentrations were low at all sites.

Recommendations

- Parameters that showed the expected response to the disturbance gradient and are recommended for inclusion in future programs were: pH, conductivity, dissolved oxygen, total nitrogen, NH_4, NO_3 and total phosphorus
- It would be beneficial to monitor different nutrient indicators, rather than just total nitrogen, as this may provide evidence of the source of the nitrogen

Site scores for water quality

Indicator scores

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Algae

Why measure algae?

- Algae (diatoms) are abundant in most streams and respond rapidly to changed conditions
- They are relatively easy to sample, and their tolerance to environmental conditions is known for many species due to the wide distribution of many taxa
- Algal abundance (e.g. measured as chlorophyll concentration) and isotopic signatures can detect nutrient enrichment and nutrient sources

What was measured?

Benthic algae were collected from rocky substrate at each site, based on which the following five algal indicators were examined:

- Chlorophyll a and filamentous algae, which measure algal abundance
- Biological Diatom Index (IBD) and Specific Pollution Sensitivity Index (IPS), which take account of the tolerance of different taxa to declining water quality
- $\delta^{15}N$ enrichment in filamentous algae was used to indicate likely nutrient enrichment from agriculture and untreated human wastes.

Benchmarks were established based on international literature.

What do the results show?

All indicators showed a response to urbanization or agriculture, except for filamentous algae. $\delta^{15}N$ values increased with the proportion of agriculture in the catchment, while Chlorophyll a concentrations indicated higher algal abundances in urban catchments. Sensitivity indices IBD and IPS both declined strongly with urbanization.

Unsurprisingly given the elevated nutrient concentrations, algal indicators scored poorly at many sites. This included both measures of community structure (IBD and IPS) and elevated $\delta^{15}N$ ratios in algal tissue samples, which supports the role of human or animal waste in increasing nitrogen enrichment. This suggests that efforts to reduce nutrient loads, through decreased urban and agricultural runoff, may improve river health.

Site scores for diatoms

Indicator scores

Recommendations

- Algal indices showed clear and consistent relationships with levels of agriculture and urbanization.
- Nevertheless, existing (international) sensitivity grades should be refined based on further studies of Chinese conditions.
- Considerable taxonomic expertise is required to utilise these algal indicators. These requirements, and associated costs need to be weighed up against alternative indicator groups in selecting suitable indicators for inclusion in a monitoring program.

Algae

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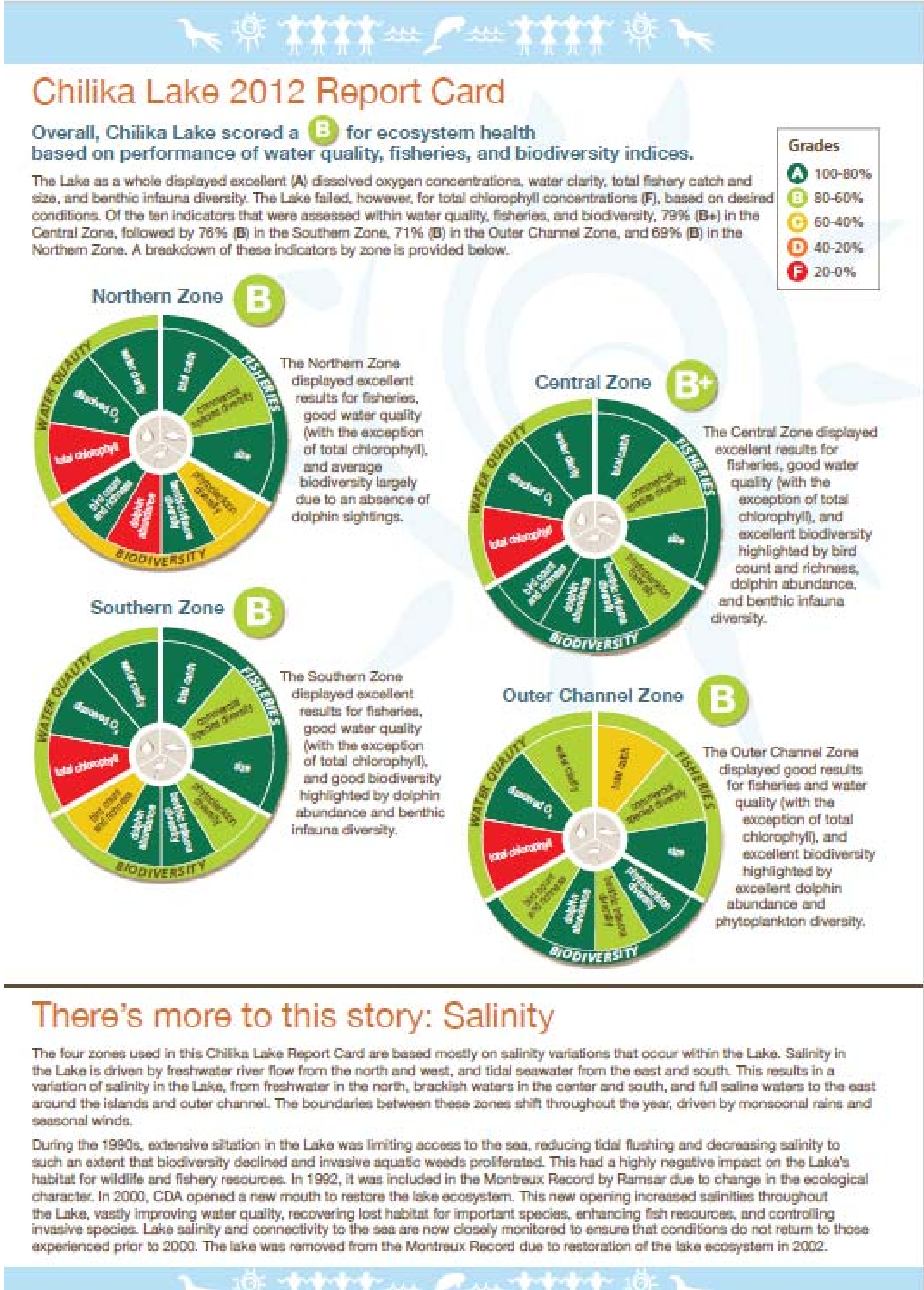
Chilika Lake Report Card, India (IAN)


Chilika Lake 2012 Report Card

Overall, Chilika Lake scored a B for ecosystem health based on performance of water quality, fisheries, and biodiversity indices.

The Lake as a whole displayed excellent (A) dissolved oxygen concentrations, water clarity, total fishery catch and size, and benthic infauna diversity. The Lake failed, however, for total chlorophyll concentrations (F), based on desired conditions. Of the ten indicators that were assessed within water quality, fisheries, and biodiversity, 79% (B+) in the Central Zone, followed by 76% (B) in the Southern Zone, 71% (B) in the Outer Channel Zone, and 69% (B) in the Northern Zone. A breakdown of these indicators by zone is provided below.

Grades
A 100-80%
B 80-60%
C 60-40%
D 40-20%
F 20-0%

Northern Zone B

The Northern Zone displayed excellent results for fisheries, good water quality (with the exception of total chlorophyll), and average biodiversity largely due to an absence of dolphin sightings.

Central Zone B+

The Central Zone displayed excellent results for fisheries, good water quality (with the exception of total chlorophyll), and excellent biodiversity highlighted by bird count and richness, dolphin abundance, and benthic infauna diversity.

Southern Zone B

The Southern Zone displayed excellent results for fisheries, good water quality (with the exception of total chlorophyll), and good biodiversity highlighted by dolphin abundance and benthic infauna diversity.

Outer Channel Zone B

The Outer Channel Zone displayed good results for fisheries and water quality (with the exception of total chlorophyll), and excellent biodiversity highlighted by excellent dolphin abundance and phytoplankton diversity.

There's more to this story: Salinity

The four zones used in this Chilika Lake Report Card are based mostly on salinity variations that occur within the Lake. Salinity in the Lake is driven by freshwater river flow from the north and west, and tidal seawater from the east and south. This results in a variation of salinity in the Lake, from freshwater in the north, brackish waters in the center and south, and full saline waters to the east around the islands and outer channel. The boundaries between these zones shift throughout the year, driven by monsoonal rains and seasonal winds.

During the 1990s, extensive siltation in the Lake was limiting access to the sea, reducing tidal flushing and decreasing salinity to such an extent that biodiversity declined and invasive aquatic weeds proliferated. This had a highly negative impact on the Lake's habitat for wildlife and fishery resources. In 1992, it was included in the Montreux Record by Ramsar due to change in the ecological character. In 2000, CDA opened a new mouth to restore the lake ecosystem. This new opening increased salinities throughout the Lake, vastly improving water quality, recovering lost habitat for important species, enhancing fish resources, and controlling invasive species. Lake salinity and connectivity to the sea are now closely monitored to ensure that conditions do not return to those experienced prior to 2000. The lake was removed from the Montreux Record due to restoration of the lake ecosystem in 2002.

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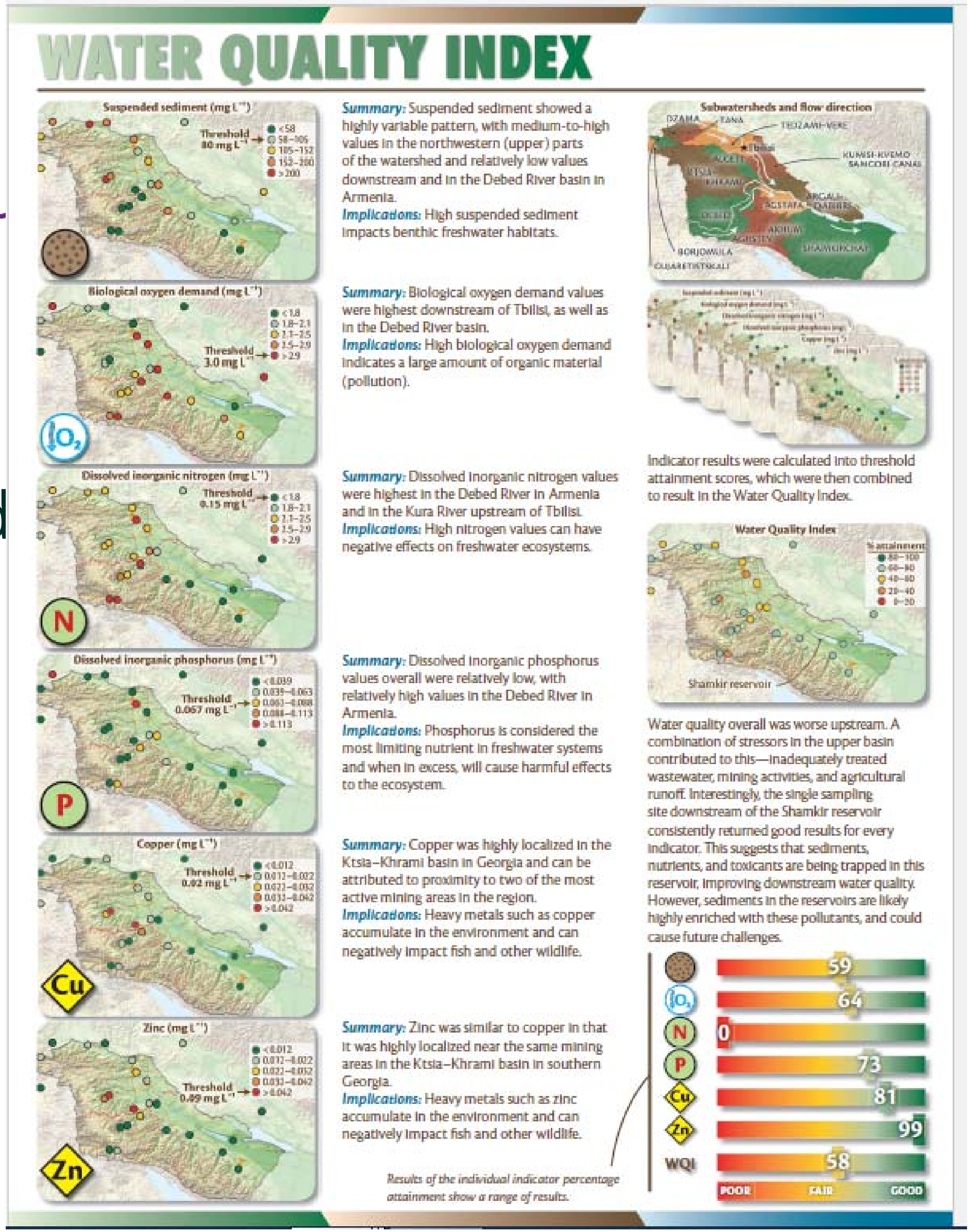
Kura River Basin Report Card, Georgia, Armenia and Azerbaijan (IAN)



WATER QUALITY INDEX

Suspended sediment (mg L⁻¹)

Summary: Suspended sediment showed a highly variable pattern, with medium-to-high values in the northwestern (upper) parts of the watershed and relatively low values downstream and in the Debed River basin in Armenia.
Implications: High suspended sediment impacts benthic freshwater habitats.

Biological oxygen demand (mg L⁻¹)

Summary: Biological oxygen demand values were highest downstream of Tbilisi, as well as in the Debed River basin.
Implications: High biological oxygen demand indicates a large amount of organic material (pollution).

Dissolved inorganic nitrogen (mg L⁻¹)

Summary: Dissolved inorganic nitrogen values were highest in the Debed River in Armenia and in the Kura River upstream of Tbilisi.
Implications: High nitrogen values can have negative effects on freshwater ecosystems.

Dissolved inorganic phosphorus (mg L⁻¹)

Summary: Dissolved inorganic phosphorus values overall were relatively low, with relatively high values in the Debed River in Armenia.
Implications: Phosphorus is considered the most limiting nutrient in freshwater systems and when in excess, will cause harmful effects to the ecosystem.

Copper (mg L⁻¹)

Summary: Copper was highly localized in the Ktsia–Khrami basin in Georgia and can be attributed to proximity to two of the most active mining areas in the region.
Implications: Heavy metals such as copper accumulate in the environment and can negatively impact fish and other wildlife.

Zinc (mg L⁻¹)

Summary: Zinc was similar to copper in that it was highly localized near the same mining areas in the Ktsia–Khrami basin in southern Georgia.
Implications: Heavy metals such as zinc accumulate in the environment and can negatively impact fish and other wildlife.

Subwatersheds and flow direction

Indicator results were calculated into threshold attainment scores, which were then combined to result in the Water Quality Index.

Water Quality Index

Water quality overall was worse upstream. A combination of stressors in the upper basin contributed to this—inadequately treated wastewater, mining activities, and agricultural runoff. Interestingly, the single sampling site downstream of the Shamkir reservoir consistently returned good results for every indicator. This suggests that sediments, nutrients, and toxicants are being trapped in this reservoir, improving downstream water quality. However, sediments in the reservoirs are likely highly enriched with these pollutants, and could cause future challenges.

Results of the individual indicator percentage attainment show a range of results.

Validation and review

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- Combination of…
    - Indicators
    - Thresholds
    - Scoring
    - Weighting
    - Grading

…can result in very different end products!

- How do you know you've got it right?
    - Expert opinion (e.g. independent science panels)
    - Regular review mechanisms
    - International peer review (publishing in research journals) – who's done this?

PLOS | ONE

RESEARCH ARTICLE

Developing a Social, Cultural and Economic Report Card for a Regional Industrial Harbour

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An Ecosystem Health Index for a large and variable river basin: Methodology, challenges and continuous improvement in Queensland's Fitzroy Basin

CrossMark

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Integration of science and monitoring of river ecosystem health to guide investments in catchment protection and rehabilitation

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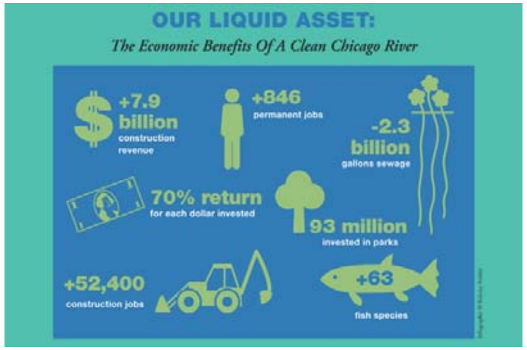
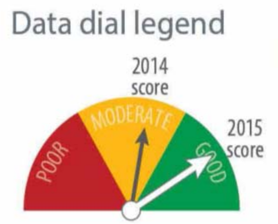
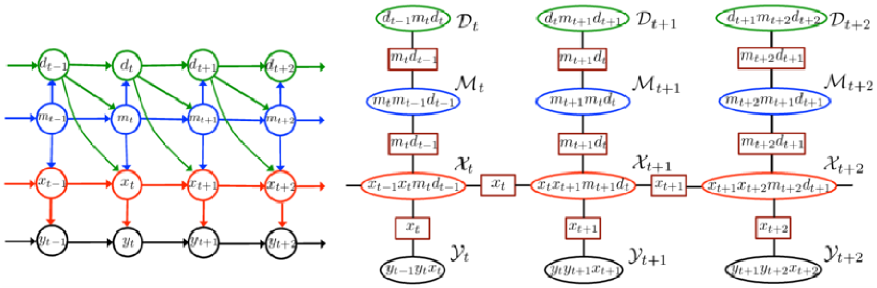
Oh I know, that was exhausting. Here's some music. And another game.

Activity 4: Choose your poison

Create either a Math Guru or Communication Guru version representing an element of your report card metrics.







Discussion and Questions

- **Is there a common set of indicators and could this be used for cross initiative reporting?**
- **Should we have a reference document that covers the various options for metrics and scoring?**
- **What are some of the emerging methods for report card scoring?**
  How often are these reviewed?
- **If we identify a need to change our metrics, how can this be done smoothly and how do we communicate this to end users?**
  Has anyone changed indicators or grading methods after one or more years?
  What was the incentive / justification?
  How did you manage communications?