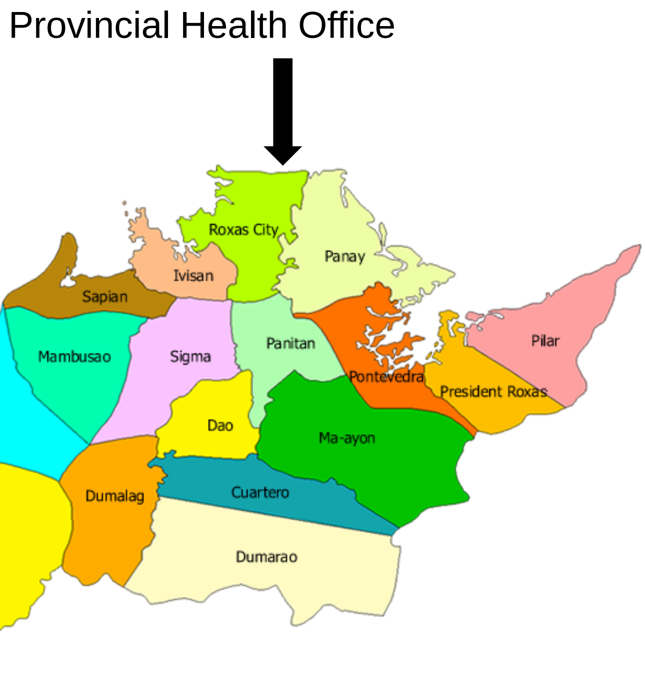
Water Quality Testing and Water Use Assessments in Capiz Province, Philippines

Capiz Assessment and Water Solutions

Study Area: Capiz Province

- Population: 700,000
- Roxas City: 132,000 people
- 16 municipalities
- Main economies
  - Fishing
  - Farming



Capiz Provincial Health Office

- Provincial Health Officer: Dr. Jarvis Punsalan
- Sanitary Engineer: Jane Delos Reyes

Capiz Water Sources

UN Designation	Unimproved	Improved		
Philippines Designation	Doubtful	Level 1	Level 2	Level 3




Project Scope

- Selective testing of water sources in 16 municipalities of Capiz Province for EC-Kit verification and water quality mapping
- Selective testing of water sources to determine the accuracy of the H_2S and Easygel tests and to determine their potential as complementary EC-Kit tests
- Village site visits in each municipality for source and community water use assessments
- Modeling for Panay River water resources planning and management

Comparison of EC-Kit with Quanti-Tray®: Testing, Verification, and Drinking Water Quality Mapping

Patty Chuang

Research Objectives

- To determine the risk level data for drinking water sources according to *Escherichia coli* and total coliform levels in the province under different conditions.
- To verify the EC-Kit under different water source conditions.
- To create a map of the water quality results from EC-Kit and Quanti-Tray®.

Background: The EC-Kit and Quanti-Tray ®

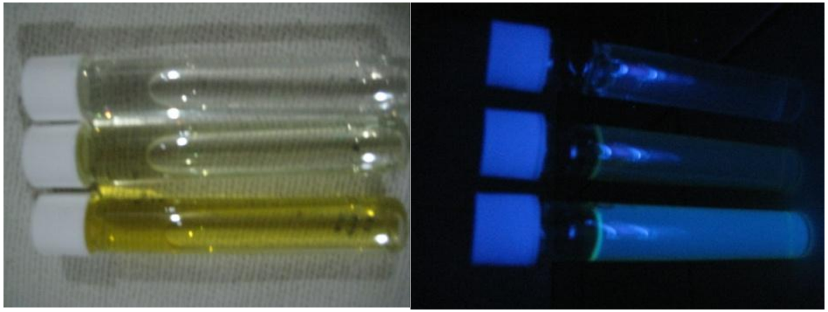
- The EC-Kit
  - Simple and inexpensive kit
  - Two complementary tests for *E. coli*
    - Colilert 10 mL Presence/Absence test
    - 3M's Petrifilm™ Enumerative test

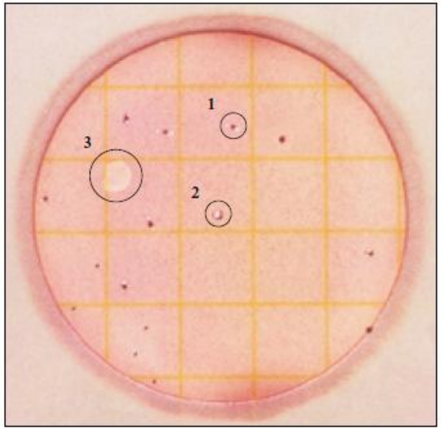
- IDEXX Quanti-Tray® and Quanti-Tray®/2000
  - Enzyme substrate coliform tests
  - Use semi-automated quantification methods based on the Standard Methods Most Probable Number (MPN) model

- Provides bacterial counts of up to 200.5 MPN /100 mL of sample (or 2419 MPN /100 mL for Quanti-Tray/2000)

Sample Analysis

- EC-Kit Test Results





- Quanti-Tray Test Results

Sample Analysis

- *E.coli* counts from Colilert and Petrifilm enable the determination of different levels of risk

EC-Kit Results		Risk Level Categories	
Colilert *E. coli* Result (Metcalf, 2006)	Petrifilm *E. coli* Result (Metcalf, 2006)	Risk Level (WHO, 1997)	*E.coli* in sample (coliform forming unit per 100 mL) (WHO, 1997)
Absent (clear = below detection)	0	Conformity	< 1
Absent (clear = below detection)	0	Low	1-10
Present (yellow, blue fluorescence)	0	Intermediate	10-100
Present (yellow, blue fluorescence)	1-10 (blue with gas bubbles count)	High	100-1000
Present (yellow, blue fluorescence)	> 10 (blue with gas bubbles count)	Very High	> 1000

(Adapted from WHO, 1997, replacing "thermotolerant bacteria" with "*E. coli*") (Metcalf, 2006)

Water Quality Test Results

- 561 water samples
  - 521 water samples collected in Capiz Province
  - 40 water samples collected from the Charles River
- Each sample was tested in the field using the two component tests of the EC-Kit and Quanti-Tray®

- For all statistical analyses, STATA: Data Analysis and Statistical Software (Version 11.0) was used

Chi-square test for Capiz Water Samples

	Risk Level	Quanti-Tray® Most Probable Number: Conformity/Low/Intermediate	Quanti-Tray® Most Probable Number: High/Very High	Total
Petrifilm™	Low/Conformity/Intermediate	353	19	372
	High/Very High	43	106	149
	Total	396	125	521

χ^2 =254.3837
Pr = 0.000

		Quanti-Tray®: Presence	Quanti-Tray®: Absence	Total
Colilert	Presence	242	32	274
	Absence	101	146	247
	Total	343	178	521

χ^2 =129.923
Pr = 0.000

	Risk Level	Quanti-Tray® Most Probable Number: Conformity/Low	Intermediate	High/Very High	Total
EC-Kit	Low/Conformity	230	13	4	247
	Intermediate	76	34	15	125
	High/Very High	13	30	106	149
	Total	319	77	125	521

χ^2 =336.2617
Pr = 0.000

2x2 Frequency Distribution Table for Capiz

	Risk Level	Quanti-Tray® Most Probable Number: Conformity/Low/Intermediate	High/Very High	Total
Petrifilm™	Low/Conformity/Intermediate	68%	4%	71%
	High/Very High	8%	20%	29%
	Total	76%	24%	100%

True Results = 88%

		Quanti-Tray®: Presence	Absence	Total
Colilert	Presence	46%	6%	53%
	Absence	19%	28%	47%
	Total	66%	34%	100%

True Results = 74%

	Risk Level	Quanti-Tray® Most Probable Number: Conformity/Low	Intermediate	High/Very High	Total
EC-Kit	Low/Conformity	44%	2%	1%	47%
	Intermediate	15%	7%	3%	24%
	High/Very High	2%	6%	20%	29%
	Total	61%	15%	24%	100%

True Results = 71%

Calculating Proportional Reduction in Error (λ)

- A measure of "how good one becomes at making predictions"
- Initial prediction is based on current UN water source level designation:
  - Unimproved sources: High/Very High Risk Level (Presence)
  - Improved sources: Conformity/Low Risk Level (Absence)

$$\lambda = \frac{(Error\ w/o\ conditional\ info) - (Error\ w/conditional\ info)}{Error\ w/o\ conditional\ info}$$

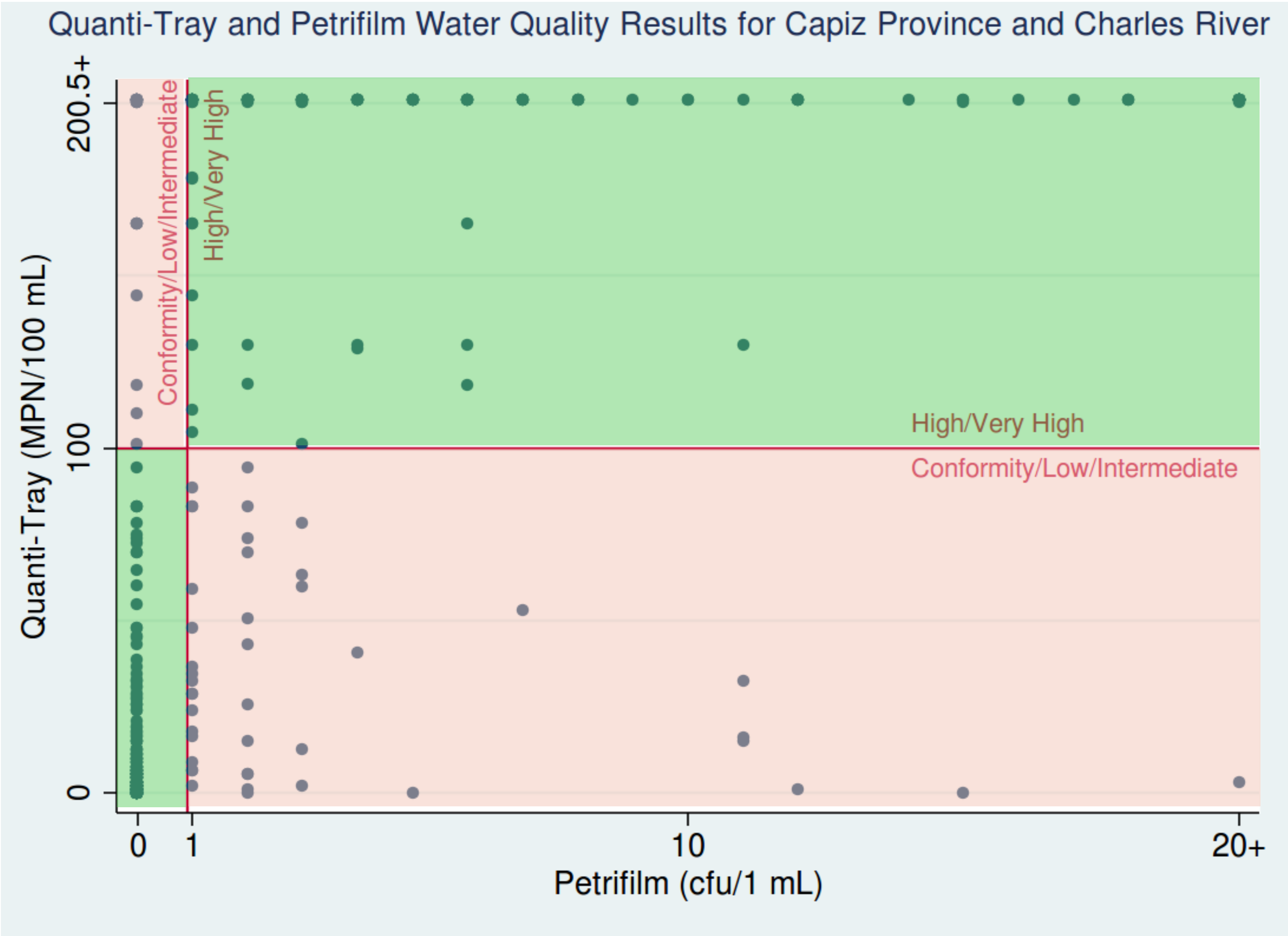
New Test	Standard Method: *Presence*	Standard Method: *Absence*
Presence		
Absence		

- **BUT** not only interested in specific categories, also in ensuring the new, field-based tests err on the side of caution…

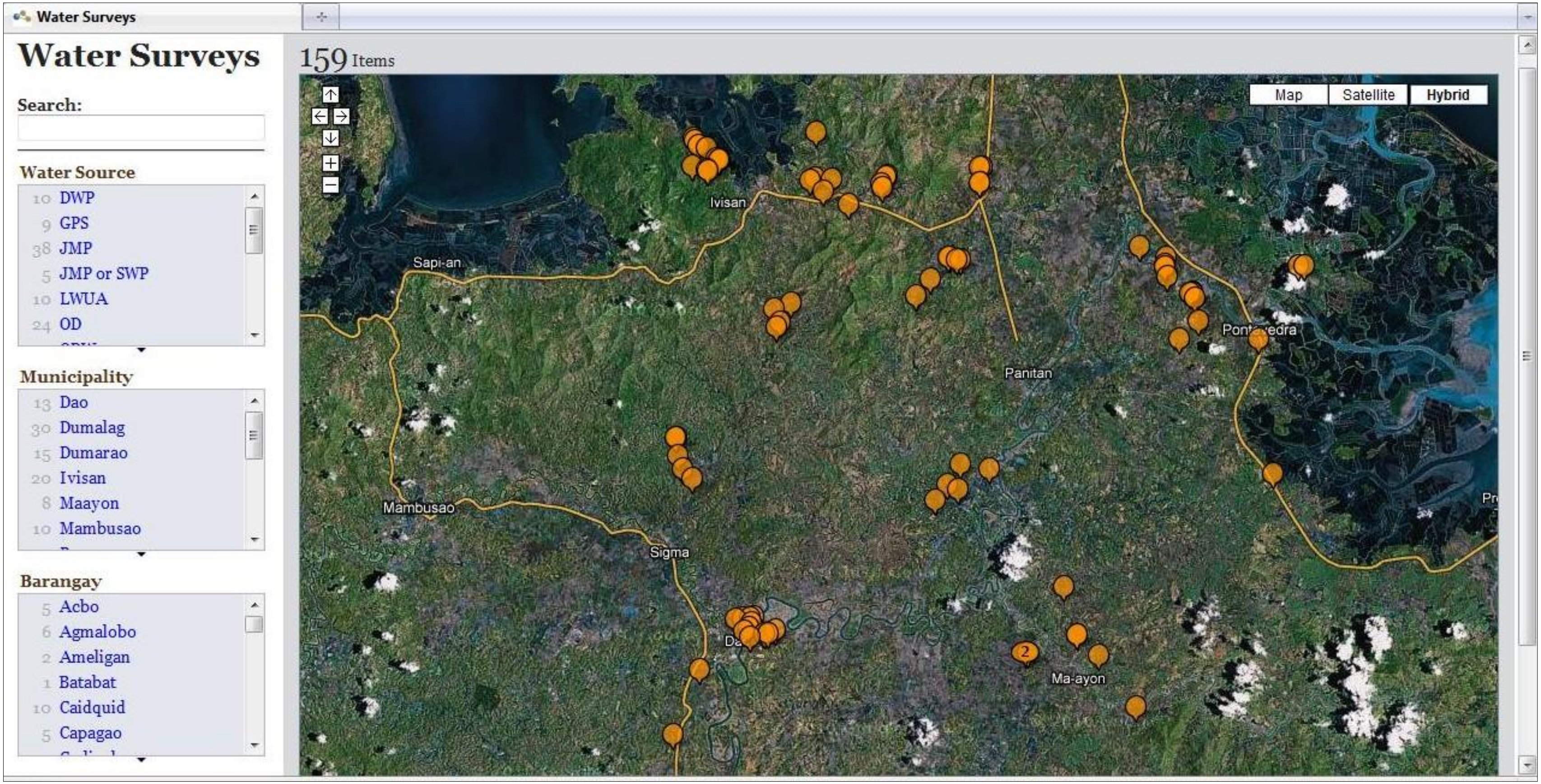
		Standard Method Test		
		Conformity/Low	*Intermediate*	*High/Very High*
New Test	*Conformity/Low*			
	Intermediate			
	High/Very High			

Proportional Reduction in Error

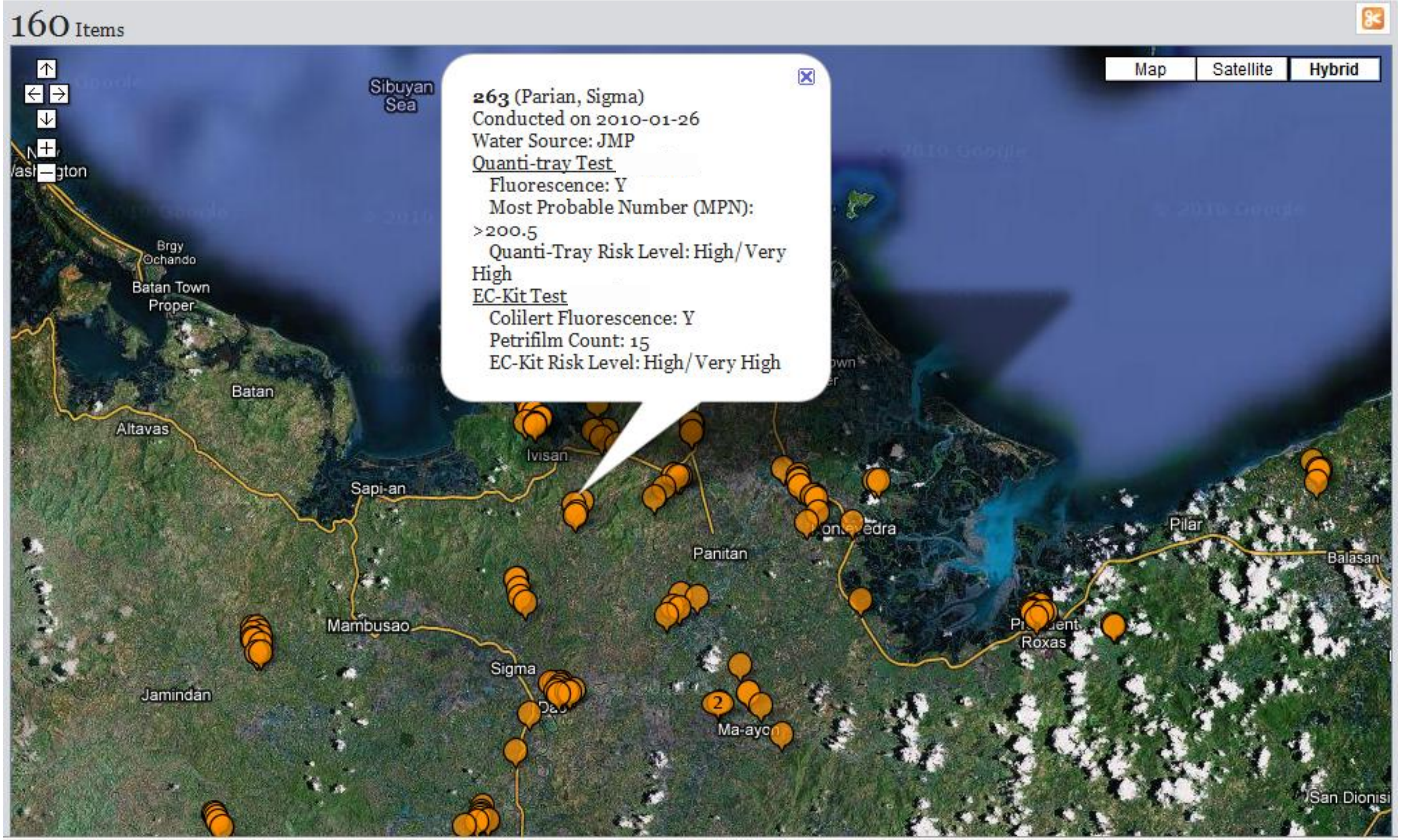
Tests	Error	Proportional Reduction in Error (λ)
Unimproved + Quanti-Tray	15%	
Unimproved + Colilert	12%	25%
Unimproved + Petrifilm	37%	-138%
Unimproved + EC-Kit	6%	63%
Improved + Quanti-Tray	64%	
Improved + Colilert	27%	58%
Improved + Petrifilm	39%	39%
Improved + EC-Kit	6%	60%


Quanti-Tray and Petrifilm Water Quality Results for Capiz Province and Charles River
Quanti-Tray (MPN/100 mL)
200.5+
100
0
Conformity/Low/Intermediate
High/Very High
High/Very High
Conformity/Low/Intermediate
0
1
10
20+
Petrifilm (cfu/1 mL)

Water Quality Mapping



Water Quality Mapping



Conclusion

Conclusion

- Each component of EC-Kit and the entire kit is correlated to Quanti-Tray® in a statistically significant way (chi-square test)
- We can make better predictions with the use of just Colilert, but not Petrifilm (due to detection limit)
- A combination of both tests in the form of the EC-Kit allows for best predictions
- Proportional reduction in error in using the EC-Kit is 62.5% for unimproved water sources and 59.8% for improved water sources

Recommendations for Future Studies

EC-Kit

- Modification of EC-Kit Instructions
- Training and follow-up

Future Studies

- Better detection: Use of Quanti-Tray® 2000 to provide bacterial counts of up to 2419 MPN / 100 mL

Water Quality Mapping

- Allow inputs for various tests, have different risk level colors per location

New potential tests for EC-Kit:

Hydrogen Sulfide (H_2S) Test

Easygel Test

Water Quality Assessment

Stephanie Trottier

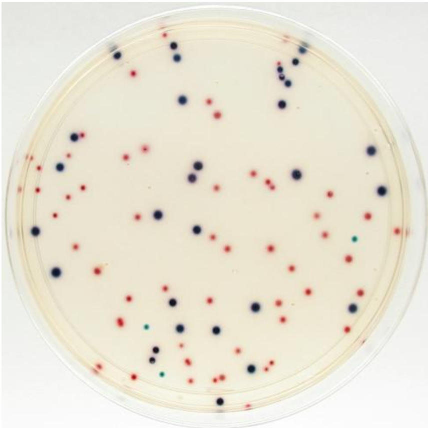
Research Objectives

- Validate the accuracy of the H_2S test, Easygel, and EC-Kit tests (Colilert and Petrifilm) against a Standard Methods test
  - Field tests in Capiz Province (vs. Quanti-Tray)
  - Laboratory tests at MIT, Cambridge (vs. Quanti-Tray and membrane filtration)
- Compare accuracy of H_2S test using different testing parameters
  - Sample volume (10, 20 and 100 mL)
  - Test reagent (Laboratory-made and HACH Pathoscreen)
- Provide Recommendations
  - Combination of tests that yield the most accurate results
  - Price and practicality/ease of use

H_2S and Easygel tests

- H_2S test
  - Presence/Absence test
  - Detects presence or absence of H_2S-producing bacteria
  - n = 203 samples

- Easygel test
  - Enumerative test
  - *E.coli* and total coliform colony counts
  - n = 83 samples



Micrology Laboratories, 2009

Colilert and Petrifilm

- **Colilert**
  - Presence/Absence test
  - Detects presence or absence of *E.coli* and total coliform
  - n = 218 samples

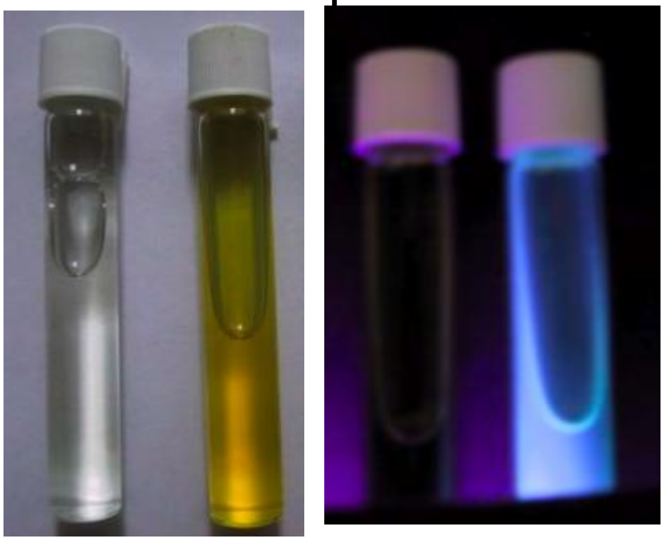


Photo credit: Robert Metcalf

- **Petrifilm test**
  - Enumerative test
  - *E.coli* and total coliform colony counts
  - n = 218 samples

Work Journal, 2009

Accuracy: Statistical Analyses

- True results, false positives and false negatives

		Standard Methods Test: Presence	Standard Methods Test: Absence
New Test	+	Positive result for both testing methods	False Positive
New Test	-	False Negative	Negative result for both testing methods

- Error and Proportional Reduction in Error, λ
- Sensitivity, Specificity, Positive and Negative Predictive Values
- Chi-square test and Fisher's exact test
- Scatter Plots

Accuracy: True Results, False Positives, False Negatives

TEST	n	True Results	False Positives	False Negatives
10-mL H_2S	**203**	80%	9%	11%
20-mL H_2S	**203**	84%	10%	6%
100-mL H_2S	**202**	80%	16%	4%
20-mL HACH	**203**	79%	9%	12%
Easygel	**83**	81%	1%	17%
Colilert	**218**	83%	5%	11%
Petrifilm	**218**	67%	3%	30%

- No clear “best test”
- Need to test the accuracy of test combinations…

Accuracy: Proportional Reduction in Error, λ

- A measure of "how good one becomes at making predictions"
- Initial prediction is based on current UN water source level designation
  - Unimproved sources: High/Very High Risk Level (Presence)
  - Improved sources: Conformity/Low Risk Level (Absence)

- **BUT** not only interested in specific categories, also in ensuring the new, field-based tests err on the side of caution…

		Standard Method Test		
		Conformity/Low	*Intermediate*	*High/Very High*
New Test	*Conformity/Low*			
	Intermediate			
	High/Very High			

Accuracy: Proportional Reduction in Error, λ

COMBINATIONS	Unimproved Sources			Improved Sources		
	Error	λ	n	Error	λ	n
EC-Kit (Colilert + Petrifilm)	3.6%	51%	28	4.8%	90%	126
Petrifilm + 10-mL H_2S test	9.1%	82%	33	3.5%	93%	114
Petrifilm + 20-mL H_2S test	12.1%	-33%	33	2.4%	95%	126
Petrifilm + 100-mL H_2S test	6.1%	33%	33	1.6%	97%	125
Petrifilm + 20-mL HACH test	15.2%	-67%	33	1.6%	97%	125
Easygel + Colilert	0.0%	100%	13	0.0%	100%	28
Easygel + 10-mL H_2S test	0.0%	100%	4	0.0%	100%	18
Easygel + 20-mL H_2S test	0.0%	100%	4	0.0%	100%	19
Easygel + 100-mL H_2S test	0.0%	100%	3	0.0%	100%	19
Easygel + 20-mL HACH test	0.0%	100%	3	0.0%	100%	22

Cost

TEST	Cost/test in United States	Cost/test in Philippines
EC-Kit	~$3.00	~$3.00
10-mL H_2S	$0.07	$0.17
20-mL H_2S	$0.14	$0.33
100-mL H_2S	$0.35	$0.83
20-mL HACH	$0.59	n/a
Easygel	$1.63	n/a

➔ Other factors to include:
- Cost of test vials/bottles
- Cost of sterile sampling bags
- Freight and transportation charges

Practicality/Ease of Use

- Tests were rated based on the following criteria

  1. Ease of training for test users: testers and readers
  2. Ease of acquiring/making reagents
  3. Ease of transportation, storage, and disposal of samples and tests
  4. Ease of processing samples
  5. Short incubation times
  6. Use of electric incubator
  7. Easy-to-read results

- Scores (Very Poor: 1 to Very Good: 5) were assigned for each criterion

Practicality/Ease of Use

Criteria	H_2S test		Easygel	EC-Kit
	Lab	HACH		
Ease of training test users	5	5	4	3
Ease of acquiring/making reagents	2	5	3	2
Ease of transportation/storage/disposal of samples and tests	3	4	3	3
Ease of processing samples	5	5	4	3
Short incubation times	5	3	4	4
Use of electric incubator	5	5	5	5
Easy-to-read results	5	5	4	2
TOTAL	**30**	**32**	**27**	**22**

Recommendations and Future Studies

Recommendations, based on data presented:

- P/A test: 20-mL H_2S test
- Quantitative test: Easygel test
- Combination: Easygel + 20-mL H_2S test is the best combination, based on accuracy (TR, FP, FN, and λ), cost, and practicality/ease of use

Future studies

- Perform a larger scale Easygel verification, in conjunction with the 20-mL H_2S test
- For Easygel + 20-mL H_2S test results: refine corresponding WHO Risk Levels
- Look at test result accuracy of combination of 2 P/A tests, and find corresponding WHO Risk Levels

Recommendations for at-risk water supplies in Capiz Province

Using Water Source and Community Assessments

Molly Patrick

Primary Project Objective

- Make technical, managerial and strategic recommendations for improving water quality and management in Capiz

  - Overarching motivation to provide **useful**, **realistic** and **sustainable** recommendations for the PHO and Capizians

Fieldwork Objectives

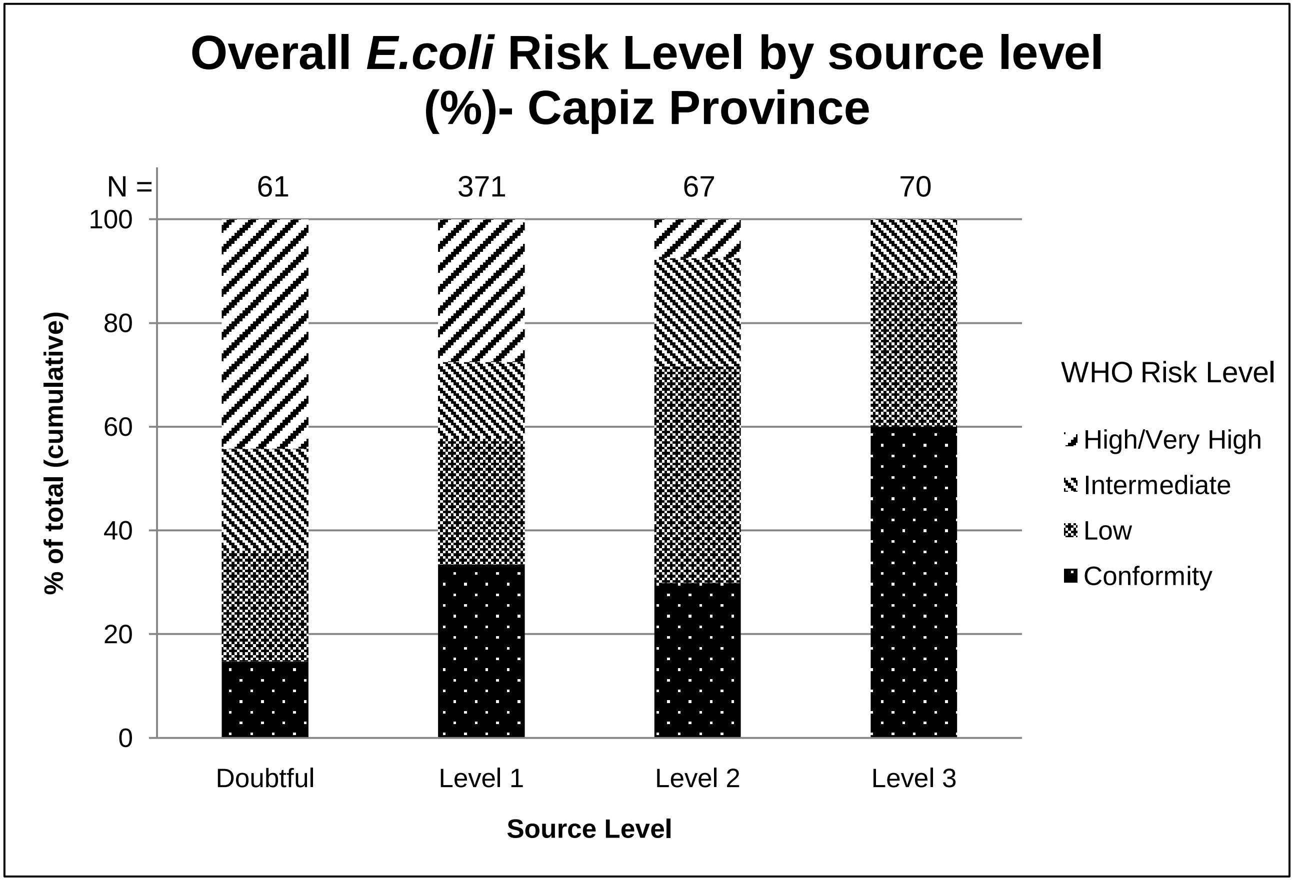
- Conduct technical assessments of identified ‘at-risk’ water supplies
  - Infrastructure
  - Hazard identification

- Use qualitative research methods to assess the non-technical issues
  - Different needs for water for different purposes
  - Perceived quality needed for different uses

Water Source and Community Assessments

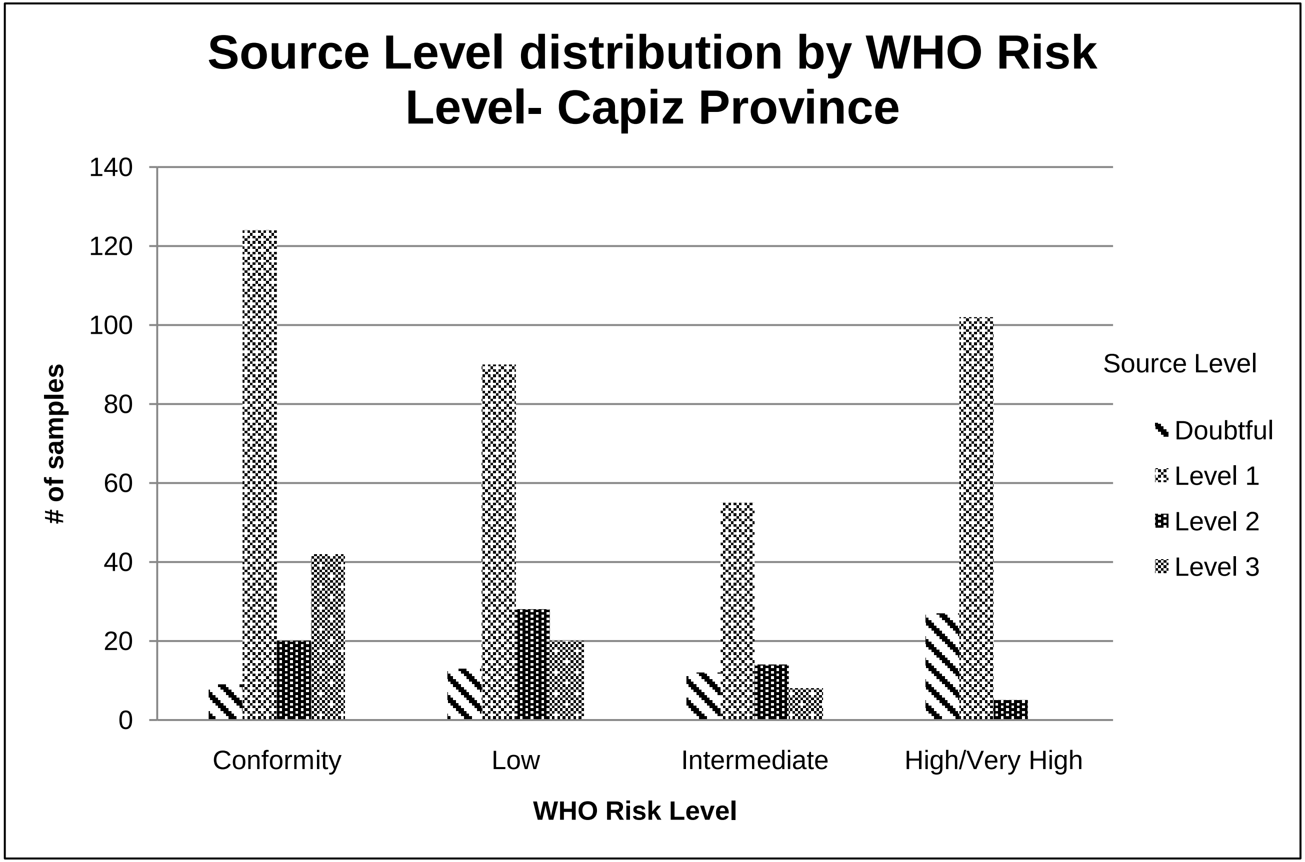
- 52 WHO Sanitary (Site) Surveys
- 51 Stakeholder Interviews and Group Discussions
- Stakeholders
  - Barangay captain/official/councilor
  - Farmer
  - Household user – mainly women

Water Quality Results- Quanti-Tray ®



Shows improving water quality with Source Level

Water Quality Results- Quanti-Tray ®

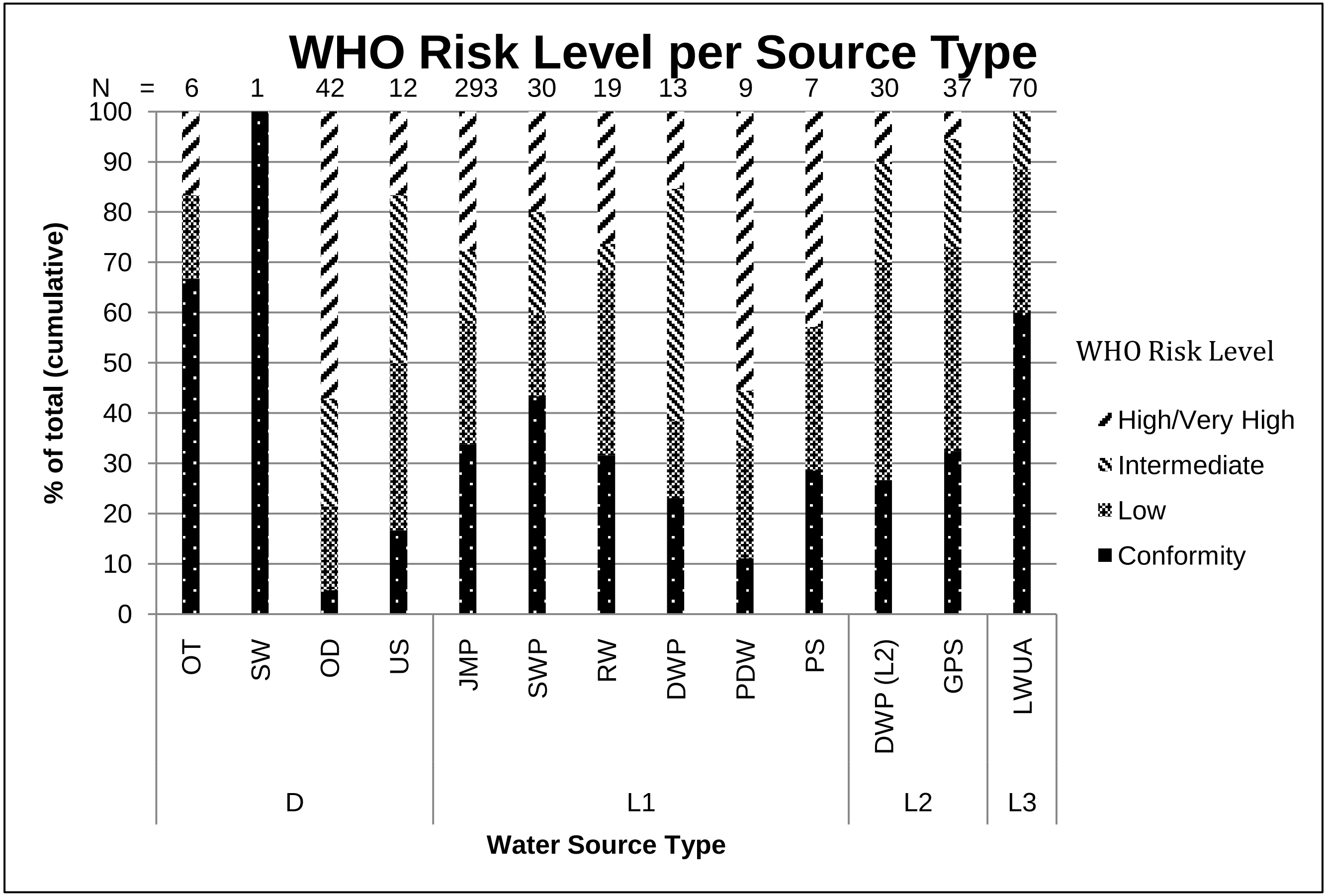


Level 1 sources show highest variability in water quality

Water Source Types

LEVEL	Water Source Code	Water Source
D	OD	Open dug well
	US	Unprotected spring
	SW	Surface water (Rivers, streams, creeks)
	OT	Others not mentioned above
L1	SWP	Shallow well with pump (<60 ft)
	JMP	Jetmatic Pump w/ or w/o motor
	DWP	Deep well with pump (>60 ft)
	PDW	Protected dug well
	PS	Protected spring w/o distribution
	RW	Rain water catchments (ferro cement tanks)
L2	GPS	Gravity protected spring w/ pipe distribution, Communal tap stands
	DWP	Deep well w/ pump w/ pipe distribution, Communal tap stands
L3	WD	Water Districts
	LWUA	Local water utilities administration
	BAWASA	*Barangay* waterworks system

Water Quality Results- Quanti-Tray ®



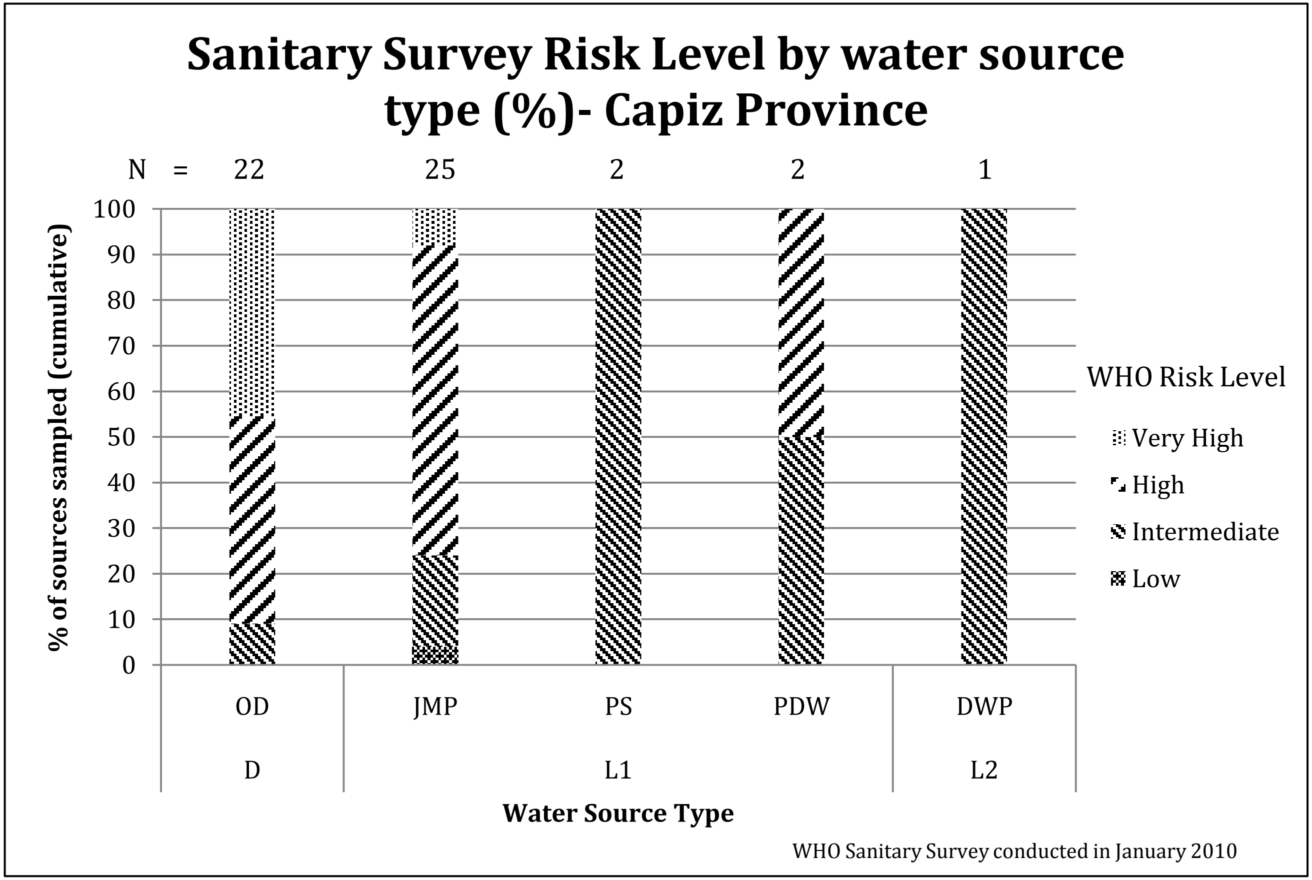
Level 2 and Level 3 source types showed 70% or more of samples in the low risk to conformity levels

WHO Sanitary Survey Results

II	Specific diagnostic information for assessment	Risk
1.	Is there a latrine within 10 m of the well?	Y/N
2.	Is the nearest latrine on higher ground than the well?	Y/N
3.	Is there any other source of pollution (e.g. animal excreta, rubbish) within 10 m of the well?	Y/N
4.	Is the drainage poor, causing stagnant water within 2 m of the well?	Y/N
5.	Is there a faulty drainage channel? Is it broken, permitting ponding?	Y/N
6.	Is the wall (parapet) around the well inadequate, allowing surface water to enter the well?	Y/N
7.	Is the concrete floor less than 1 m wide around the well?	Y/N
8.	Are the walls of the well inadequately sealed at any point for 3 m below ground?	Y/N
9.	Are there any cracks in the concrete floor around the well which could permit water to enter the well?	Y/N
10.	Are the rope and bucket left in such a position that they may become contaminated?	Y/N
11.	Does the installation require fencing?	Y/N
	Total score of risks	/11

Contamination risk score: 9–11 = very high; 6–8 = high; 3–5 = intermediate; 0–2 = low

WHO Sanitary Survey Results



77% of sources surveyed High/Very High Risk Level

Major Hazards: Unprotected Wells

- Broken or cracked platform
- Broken handpump
- Use of dirty water to prime the pump
- Improper siting
- Poor drainage

Unsanitary priming

Broken platform

Major hazards: Inadequate Site Protection

Proximity of septic tanks (or latrines) to wells

Major hazards: Inadequate Site Protection

Proximity of animals and animal wastes

Recommendations

- Step 1
  - Education, coordination
  - Training
- Step 2
  - Safe Storage containers
  - Household water treatment options
- Step 3
  - Regulatory framework
  - Management
  - Funding

Step 1- education, coordination

- Required education
  - Basic groundwater flow
  - Structural components of source types
  - Hazardous activities
- Coordination
  - Proposed sessions by municipality
  - Creation of *municipal consortiums*
    - Communication, alliances
    - Pooling of technical and financial resources
  - Enforce regular site inspections

Step 1- training

- Train local citizens as water source technicians
  - To maintain and repair public (D, L1, L2) supplies
  - Precedent
    - ‘Circuit Riders’ in Honduras
    - handpump technicians in India

  - Per municipality
  - Training by provincial water utilities
  - Volunteers or paid positions
    - Funding considerations

Step 2- HWTS

- Provide and promote the use of ‘safe storage’ containers
  - Government supplied or sold at-cost
  - Boiling or household chlorination recommended

- Explore household treatment options
  - Contact NGO’s, companies providing HWTS technologies in Philippines
  - Aquatabs, PuR, Megafresh, Biosand Filter

Step 3- regulations, management, funding

- Context and constraints
  - Decentralization of water management (1980’s)
  - Level 3: Provincial organizations
    - Local Water Utility Administrations (LWUA) and Water Districts (WD)
    - High fees
  - Public Level 1 and Level 2: No formal organization
    - Barangay council
    - General annual budget
    - No fees or small fees
  - PHO in charge of public health
    - In charge of testing
    - In charge of Sanitation Inspectors
    - Lack control over budget allocation at the barangay, municipal level

Step 3- regulations, management, funding

- Existing Regulations
  - Implementing Rules and Regulations of the Code on Sanitation of the Philippines- Chapter II Water Supply (1995)
  - Philippine National Standards for Drinking Water (2007)
- Capiz needs to develop a strategic plan for aligning their efforts with regulatory requirements
  - Quantify personnel gaps
  - “ resource gaps
  - “ funding gaps

Step 3- regulations, management, funding

- Management
  - Decentralization of water management (1980's)
  - Government roles
    - LWUA and WD can act as advisors to barangay-level organization on technical and financial management
  - Municipal consortium
    - Coordinating technicians
    - Coordinating inspection schedules

Step 3- regulations, management, funding

- Funding
  - Dedicated budgets for water improvements
  - Needs assessments
  - Funds required for:
    - safe storage
    - technicians
    - repair/maintenance of public L1
    - increased access to L2/L3
    - decreased expense of L3

Strong Municipal and Barangay-level Organization

Screening Model Optimization for Panay River Basin Planning and Management

Water Resources Assessment

John Millspaugh

Project Objective

To analyze the decision to implement infrastructure in the Panay River Basin for the purposes of flood protection, hydropower generation, and irrigating rice fields

Source:http://www.deokso.or.kr/data2000/lib/download.php?v_file=0029/200910022206520.htm&v_name=090929__Massive_flooding_in_Philippines-2.htm

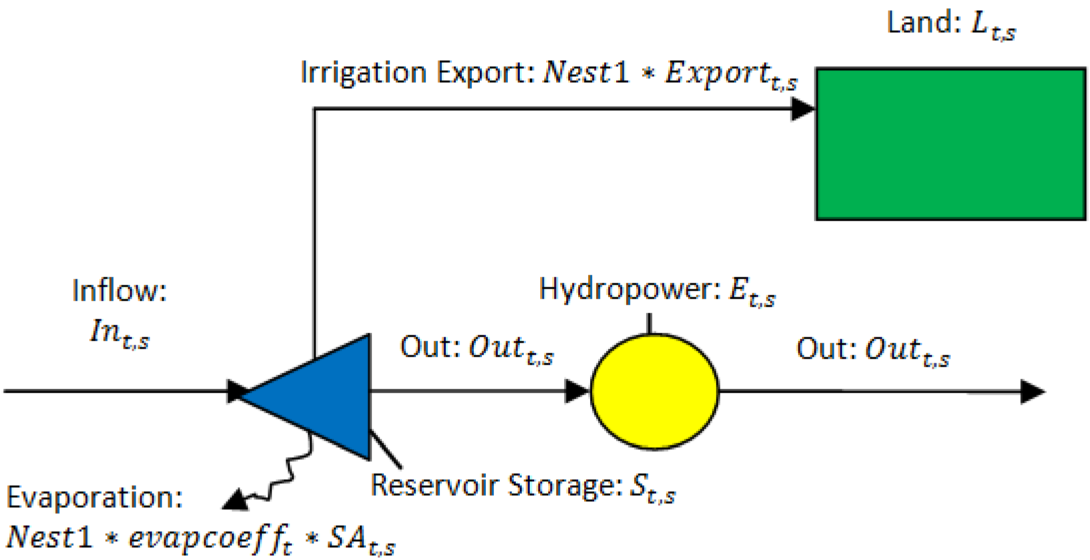
Decision Sites

Image adapted from: http://nwin.nwrb.gov.ph/Prog&Proj/JICA/studies/water_resources/studies/0605.htm

Time Increments

- 648 Time Steps, *t*
  - 600 Months, *m*
  - 48 12-hr flood times, *v*
    - 8 flood occurrences at end of June, *u*
      - 50 yr-flood occurring in the 26th year
      - 25 yr-floods occurring in the 13th and 39th years
      - 10 yr-floods occurring in the 3rd, 8th, 18th, 31st, and 43rd years

Network Diagram



Decision Variables

- Capacities of Facilities:
  - Reservoirs (CAPRes), Hydropower (CAPPower), Land (CAPLand)
- Water Management at Each Site and Time Increment:
  - Storage (S), Release (Out), Export (Export)
- Energy Produced at Each Site per Time Increment:
  - Energy (E)

Screening Model + Simulation Model

- Maximize (MPesos):

$$[\sum_{t=1}^{648}\sum_{s=1}^{4} B_{t,s}] - [\sum_{u=1}^{8}\sum_{s=1}^{4} PreventableFloodCost_{u,s}] - [SummedAmortization * C] - [O\&M]$$

- Benefits = f(hydropower, irrigation fields, flood protection)
- Amortized Cost = Facilities built, 6% interest rate assumed
- Operation and Maintenance Cost, 10% yearly of the cost of capital costs

Model Equations

Benefits

$$IrrBen_{t,s} = Nest1 * \alpha * CAPLand_s * \Delta t$$

$$\alpha = 0.004809 \frac{MPesos}{ha * month}$$

$$HydroBen_{t,s} = \beta * E_{t,s}$$

$$\beta = 0.0000125 \frac{MPesos}{KW * hr}$$

Costs

$$C = \sum_{s=1}^{4} (ResCost_s + HydroCost_s + IrrCost_s)$$

$$O\&M = 10\% * C * 50\ years$$

$$ResCost_s = k_s * CAPRes_s$$

$$HydroCost_s = q_s * CAPPower_s$$

$$IrrCost_s = 0.0292 (\frac{MPesos}{ha}) * CAPLand_s\ (ha)$$

$$PreventableFloodCost_{u,s} = \delta_s * Out_{u,s}$$

$$FloodCost_{u,j} = \omega_j * Floodflowspot_{u,j}$$

Site	Site	(MPesos/KW)
Panay 1	Panay 1	0.0304
Panay 2	Panay 2	0.0324
Badbaran	Badbaran	0.0596
Mambusao	Mambusao	0.0546

Site	δ_s Preventable Flood factor (MPesos of damage/summed MCM outflow for 3 day flood period)
Panay 1	0
Panay 2	2.3533
Badbaran	1.9817
Mambusao	2.7846

Flood Region	ω_j, Flood Factors for equation (MPesos/summed MCM for 3 days)
1	0.5663
2	0.453
3	1.377
4	1.7062
5	1.0784

Continuity

$$S_{t+1,s} = S_{t,s} + In_{t,s} - \ Nest1 * Export_{t,s} \ - \ Out_{t,s} - \ Nest1 * evapcoeff_t * SA_{t,s}$$

$$Junction_{t,1} = out_{t,2} + \ flow_{t,3} + out_{t,3} + flow_{5,t}$$

$$Junction_{t,2} = Junction_{t,1} + flow_{t,6} + flow_{t,7} + out_{t,4} + flow_{t,9}$$

$$Junction_{t,3} = Junction_{t,2} + flow_{t,10} + flow_{t,11}$$

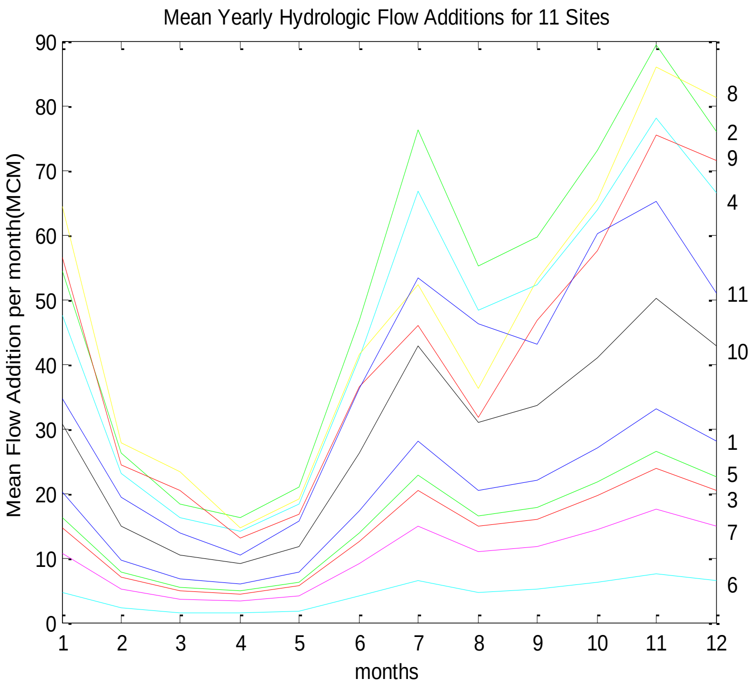
$$Floodflowspot_{t,1} = out_{t,2} + flow_{t,3}$$

$$Floodflowspot_{t,2} = out_{t,3} + flow_{t,5}$$

$$Floodflowspot_{t,3} = Junction_{t,1} + flow_{t,6}$$

$$Floodflowspot_{t,4} = out_{t,4} + flow_{t,9}$$

$$Floodflowspot_{t,5} = Junction_{t,3}$$

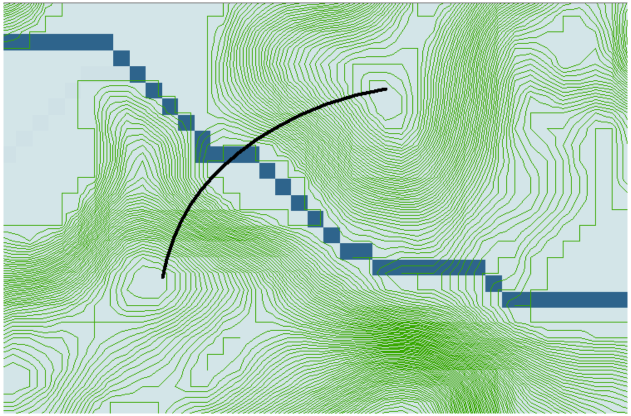


Monthly Flood Prevention:

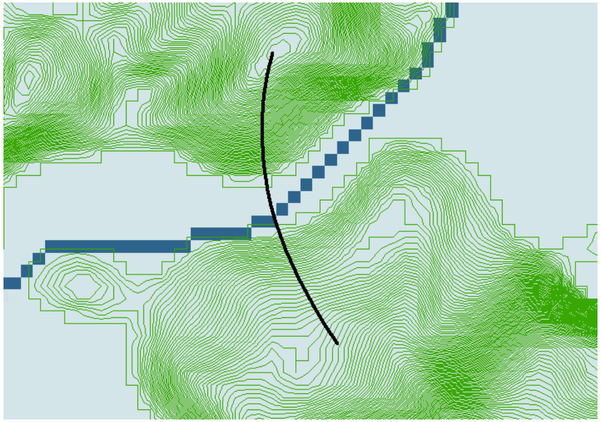
$$Floodflowspot_{m,j} \leq 907.2 \ (MCM)$$

Reservoirs

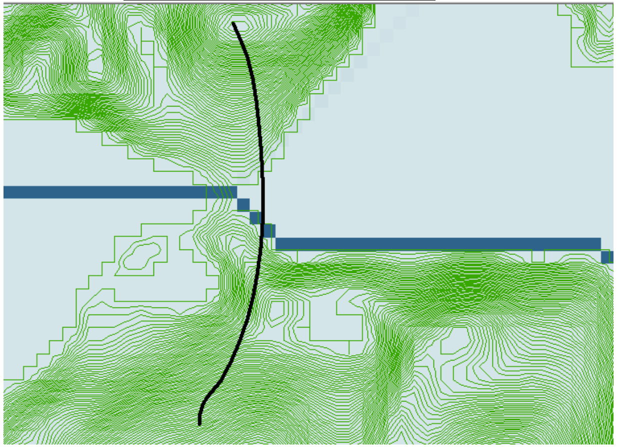
Panay 1



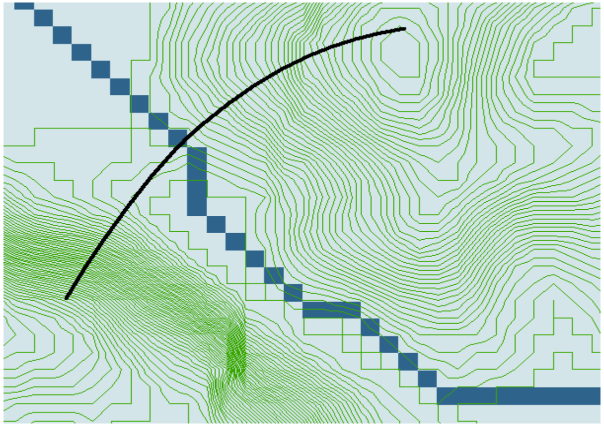
Panay 2



Badbaran



Mambusao



Constraints

Reservoirs

Site	Resmax (MCM)
Panay 1	182.22
Panay 2	535.47
Badbaran	734.55
Mambusao	743.07

Reservoir size constrained: $CAPRES_s \leq Resmax_s$

Storage constrained to capacity: $S_s \leq CAPRes_s$

Storage-Head Relationship:

$$H_{t,1} = -0.0011S_{t,1}^2 + 0.406S_{t,1} + 4.8876$$
$$H_{t,2} = -0.00003S_{t,2}^2 + 0.044S_{t,2} + 1.9019$$
$$H_{t,3} = -0.00005S_{t,3}^2 + 0.0714S_{t,3} + 2.9572$$
$$H_{t,4} = -0.00005S_{t,4}^2 + 0.0809S_{t,4} + 3.4238$$

Storage-Surface Area Relationship:

$$SA_{t,1} = 0.0484S_{t,1} + 1.4077$$
$$SA_{t,2} = 0.0765S_{t,2} + 17.054$$
$$SA_{t,3} = 0.0741S_{t,3} + 7.8962$$
$$SA_{t,4} = 0.0561S_{t,4} + 8.0456$$

Energy and Irrigation

Energy Production:

$$E_{t,s} = \gamma_1 * effic_s * Out_{t,s} * H_{t,s} * \Delta t$$

$$CAPPower_s \leq Hydromax_s$$

$$E_{t,s} \leq CAPPower_s * Nest2 * Y$$

$$Hmin_{t,s} \leq H_{t,s}$$

$$Hmaxt_{t,s} \geq H_{t,s}$$

$$Hmax_{t,s} \leq 2 * Hmin_{t,s}$$

Site	*effic*	*Hydromax (KW)*
Panay 1	0.6814	7000
Panay 2	0.5983	6000
Badbaran	0.64	2550
Mambusao	0.64	2250

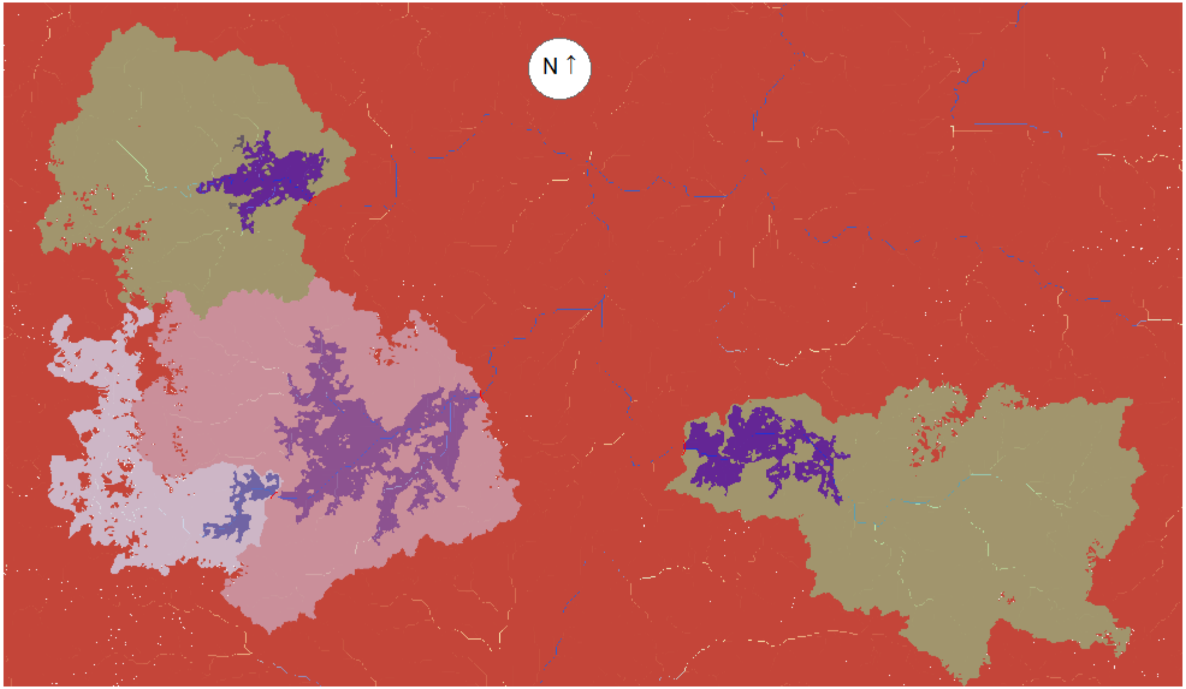
Irrigation Constraints:

$$CAPLand_s \leq Landmax_s$$

$$Export_{t,s} = watreq * CAPLand_s * \Delta t * Nest1$$

Site	Landmax (ha)
Panay 1	0
Panay 2	500
Badbaran	0
Mambusao	0

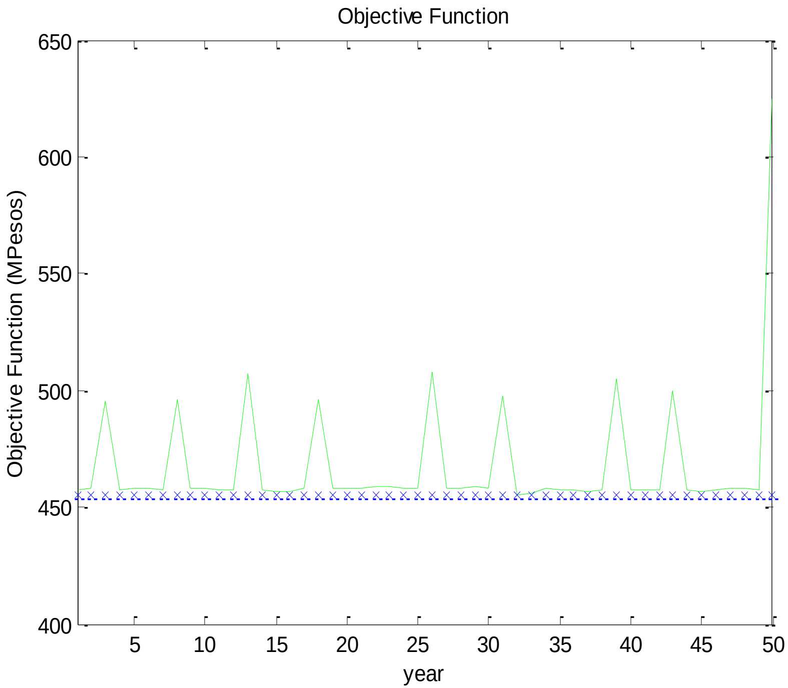
Screening Model Solution



Site	Reservoir (MCM)	Dam height (m)	Hydropower (KW)	Irrigation Land (ha)
Panay 1	88.506	32.20	2393.972	N/A
Panay 2	517.676	16.85	5609.582	500
Badbaran	206.122	15.55	2550	N/A
Mambusao	150.946	14.50	2250	N/A

Results

Objective Function



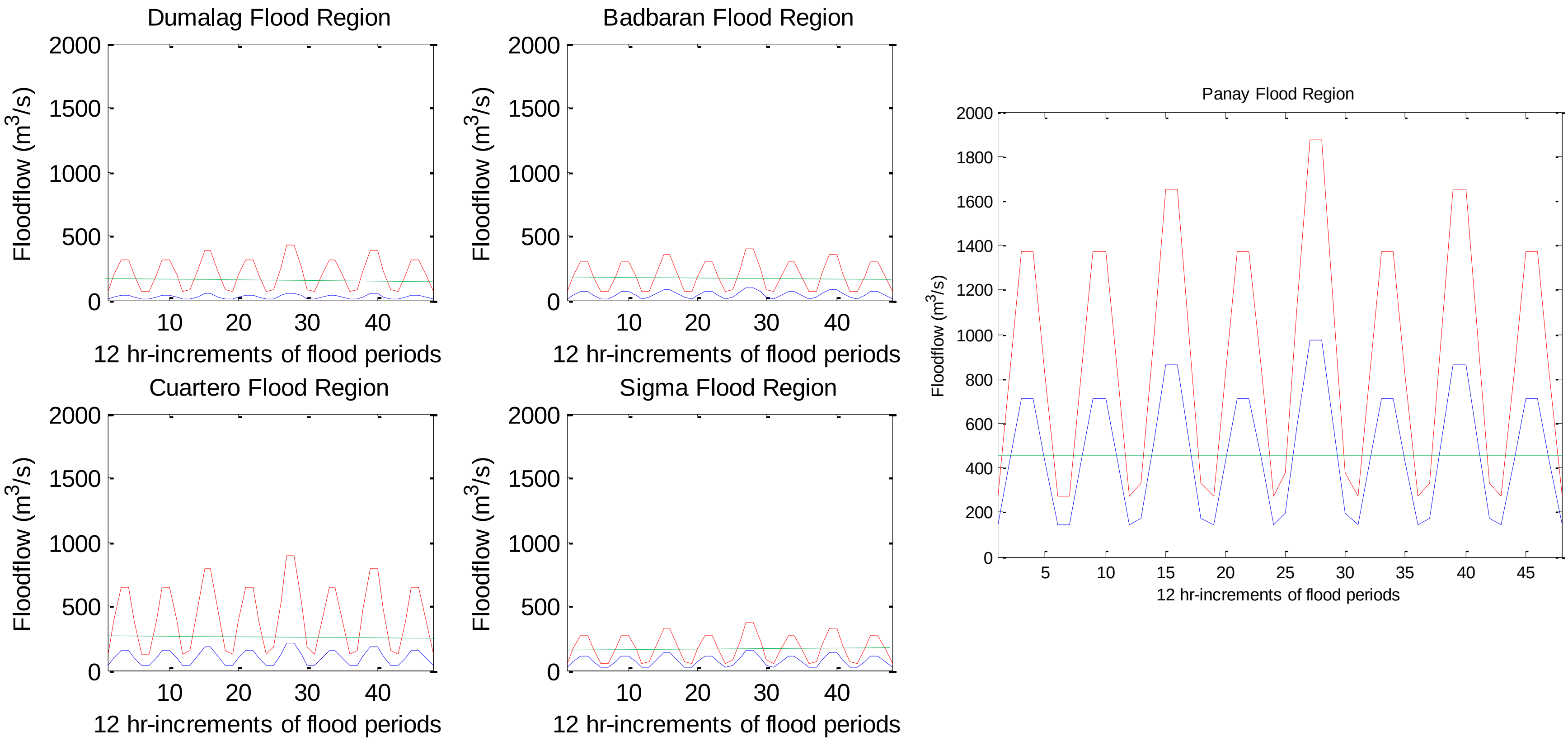
Mean Flow = 23,404 MPesos

Varying Flow = 23048 MPesos

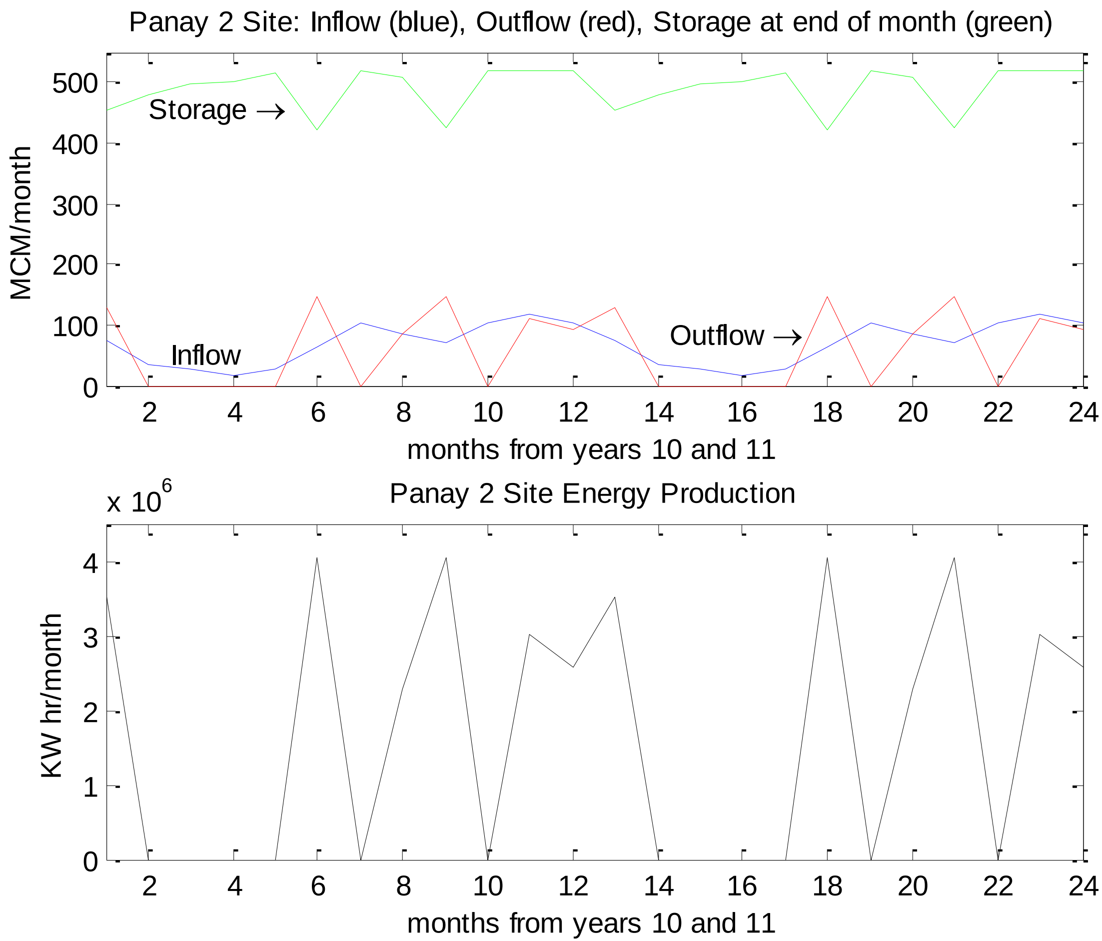
→ -1.5%

Results

Flood Control

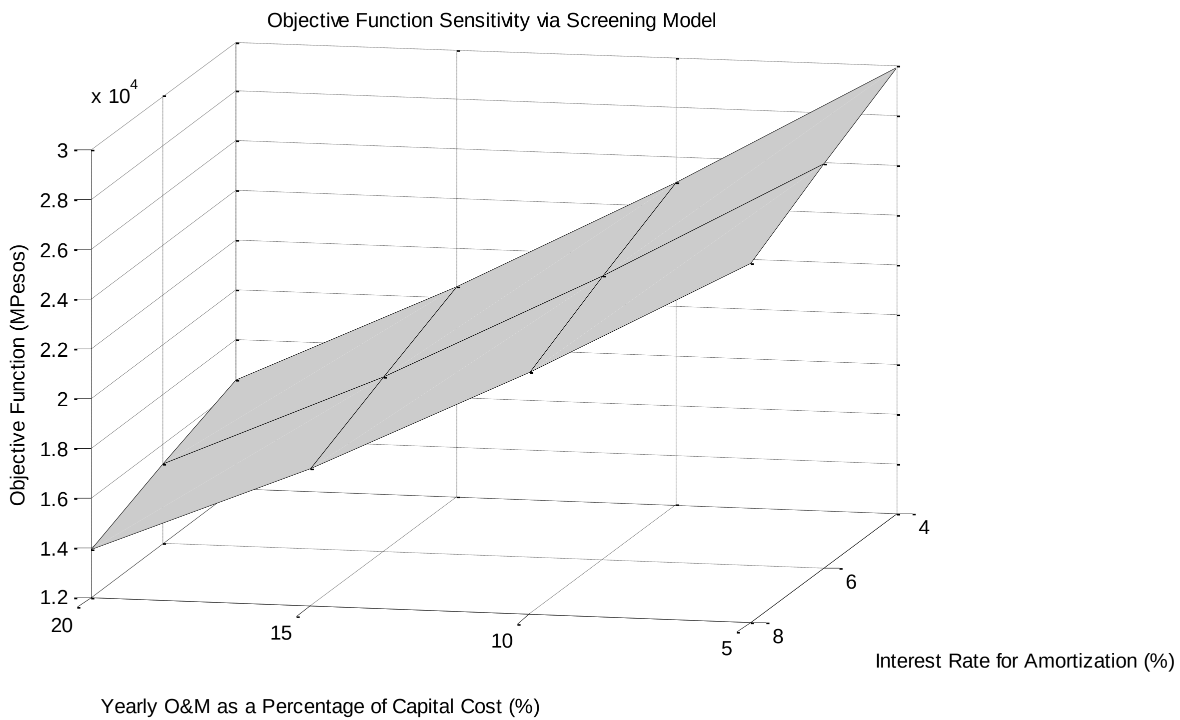


Panay 2 Monthly Flows and Energy Production



Sensitivity Analysis

- Sensitivity to O&M and Interest Rate



Sensitivity Analysis

- Sensitivity of Facility Sizes from Varying Flows

Site	Reservoir (MCM)	Dam Height (m)	Hydropower (KW)	Irrigation Land (ha)
Panay 1	+3.4%	+2.0%	+2.2%	N/A
Panay 2	0%	0%	+1.5%	0%
Badbaran	+8.0%	+5.3%	0%	N/A
Mambusao	-11.1%	-7.7%	0%	N/A

Conclusions

➔ High Potential

- Flood Protection – 46% overall reduction, 19% in Panay
- Hydropower – 91.6% of the total benefits
- Irrigation – Potential was always maximized

➔ No Hydropower/Flood Protection Tradeoff

➔ Farming

- Organic – Institutional arrangement
- Operation and Maintenance – Better Attention Needed

More Conclusions

- Other Stakeholders
  - Displaced People – Relocation and Social Cost
  - Aquaculture – Maintain/Improve River's Health
  - New Opportunities – Consistent Electricity, Breaking the Typhoon Cycle

- Data Needs

- Further Simulations

Questions?