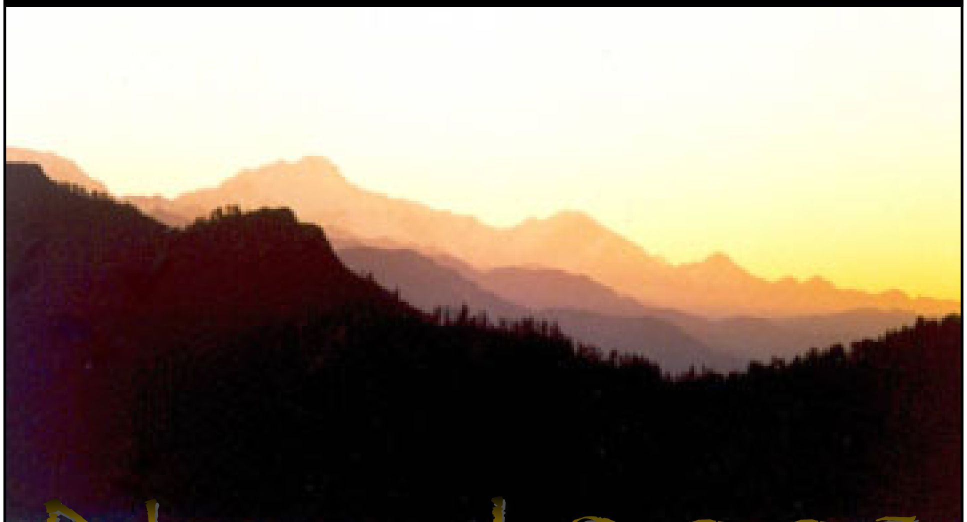
Clean Water
for Nepal, Inc



Nepal 2003

Group Members

Project Supervisor: Susan Murcott
Project Advisors: Heather Lukacs
Tommy Ngai

MEng Group

- Melanie Pincus
- Rob Dies
- Hillary Green
- Georges Tabbal
- Xanat Flores
- Saik-Choon Poh
- Mandy Richards

Sloan School

- Laura Ann Jones
- Bobby Wilson
- Steve Perreault

Friends

- Ralph Coffman
- Tetsuji Arata
- Sophie Walewijk

Outline

- Nepal Introduction
- History of MIT Nepal Projects
- Drinking Water Group
- Wastewater Group
- Questions

Nepal Statistics

- Population: ~25.8 million (2002)
- Growth rate: 2.4%
- Life expectancy: 59 years
- Children < 5 mortality: 101/1000
- Children under height for their age: 54%
- Literacy: 27.5% total population
- GDP ($PPP) per capita: $1,224/capita (USD $239/capita)

MIT Nepal Project 1999-2003

- Previous work:
  - Methodological Evaluation
  - Site Investigation (water quality testing and monitoring)
  - Technology Evaluation: (household scale drinking water treatment system design and evaluation)
  - Implementation programs (Biosand, chlorination pilot study based on CDC Safe Water System)
- This year:
  - Product Development and Marketing (Ceramic Filters/SLOAN)
  - Development and Evaluation of Novel Technology (Biosand Pitcher Filter, SC-SODIS)
  - Social Evaluation (Arsenic)
  - Wastewater (Carpet dye, Detergents, Wetlands)

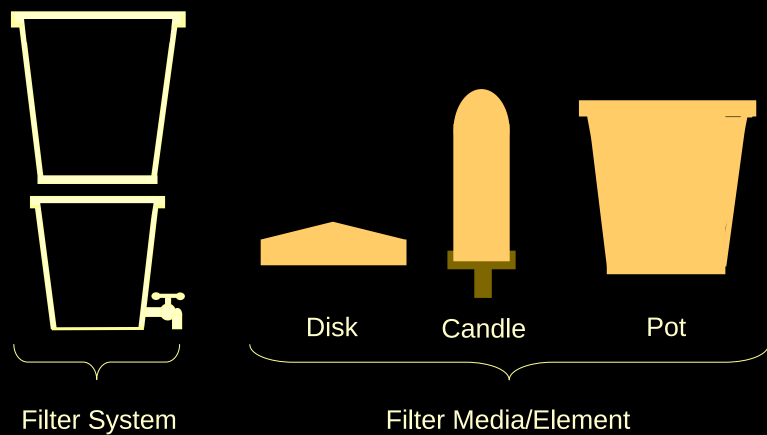
Group Projects

- Drinking Water
  - Ceramic Water Filter
  - Biosand Filter
  - Semi-Continuous SODIS
  - Arsenic
- Wastewater
  - Carpet Dyes
  - Detergents
  - Constructed Wetlands

Motivation for Clean Drinking Water

- 1.1 billion people (5 million Nepalis) lack access to improved water supply (WHO, 2000)
- Millennium Development Goal
- Human Right to Water
- Household Water Treatment

Ceramic Water Filters



Examples of Ceramic Filters

Prior MIT Ceramic Filter Work in Nepal & Nicaragua

Junko Sagara, 2000
- Study of Filtration for Point-of-Use Drinking Water Treatment in Nepal

Daniele Lantagne, 2001
- Investigation of thePotters for Peace Colloidal Silver Impregnated Ceramic Filter

Jason Low, 2002
- Appropriate Microbial Indicator Tests for Drinking Water in Developing Countries and Assessment of Ceramic Water Filters

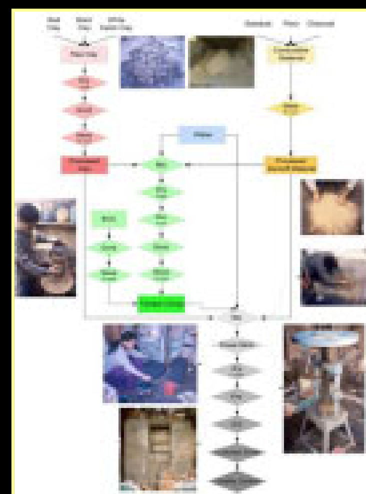
Rebeca Hwang, 2003
- Six Month Field Monitoring of Point-of-Use Ceramic Water Filter by Using H_2S Paper Strip Most Probable Number Method in San Francisco Libre, Nicaragua

2003 Nepal Ceramic Filter Research Objectives

- Continued Laboratory Research (Dies)

2003 Nepal Ceramic Filter Research Objectives

- Continued Laboratory Research (Dies)
- Documentation of Production Process (Dies)



2003 Nepal Ceramic Filter Research Objectives

- Continued Laboratory Research (Dies)
- Documentation of Production Process (Dies)
- Prototype Development (Cheung)

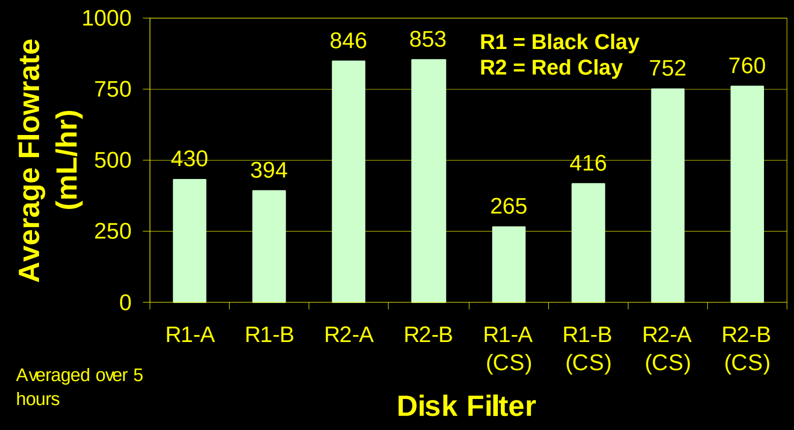
2003 Nepal Ceramic Filter Research Objectives

- Continued Laboratory Research (Dies)
- Documentation of Production Process (Dies)
- Prototype Development (Cheung)
- Preliminary Market/Consumer Analysis (Sloan Team)

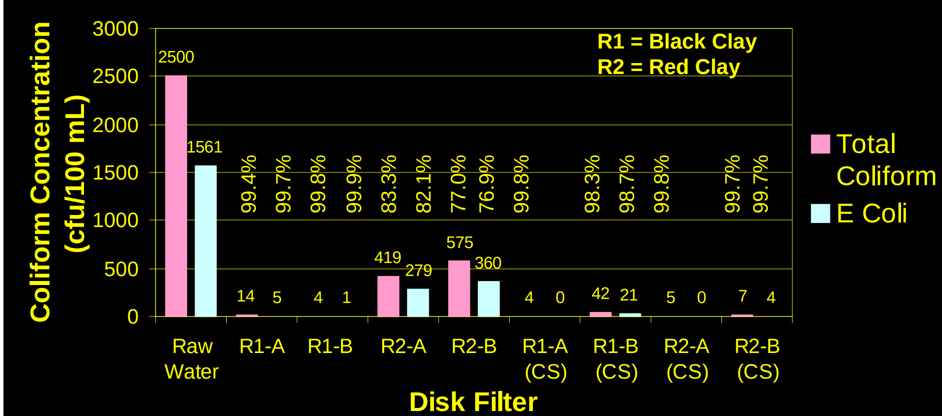
Laboratory Research

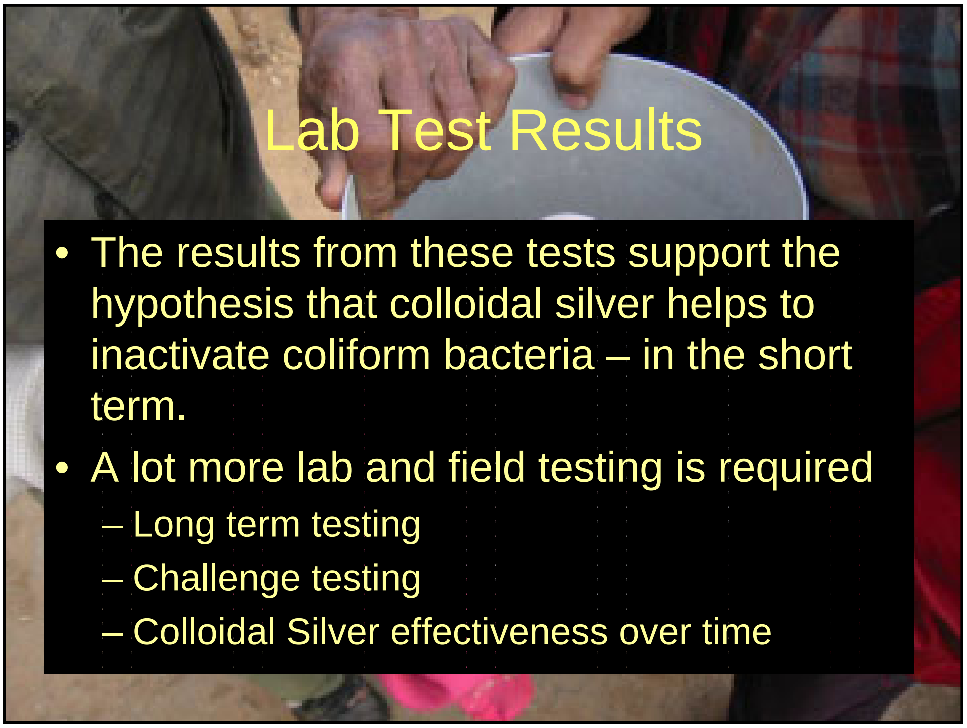
- Tested 5 candle filters:
  - Ceradyn (Katadyn), Gravidyn (Katadyn), Hari White Clay Candle (w/ & w/out colloidal silver), Hong Phuc
- Tested 3 Disks
  - Hari White Clay Disk (2 w/ colloidal silver; 2 w/out)
  - Reid Harvey Red Clay disk (2 w/ CS; 2 w/out)
  - Reid Harvey Black Clay disk (2 w/ CS; 2 w/out)
- Tested for:
  - Flow rate
  - Removal of total coliform and E. coli

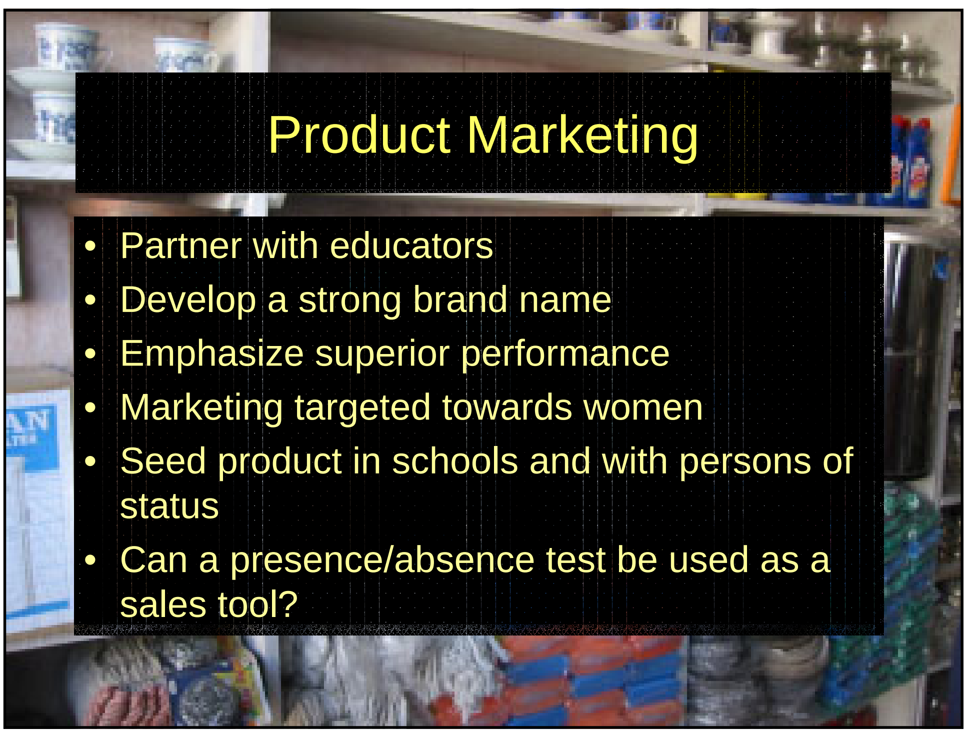
Reid Disk Filters
Average Hourly Flowrate

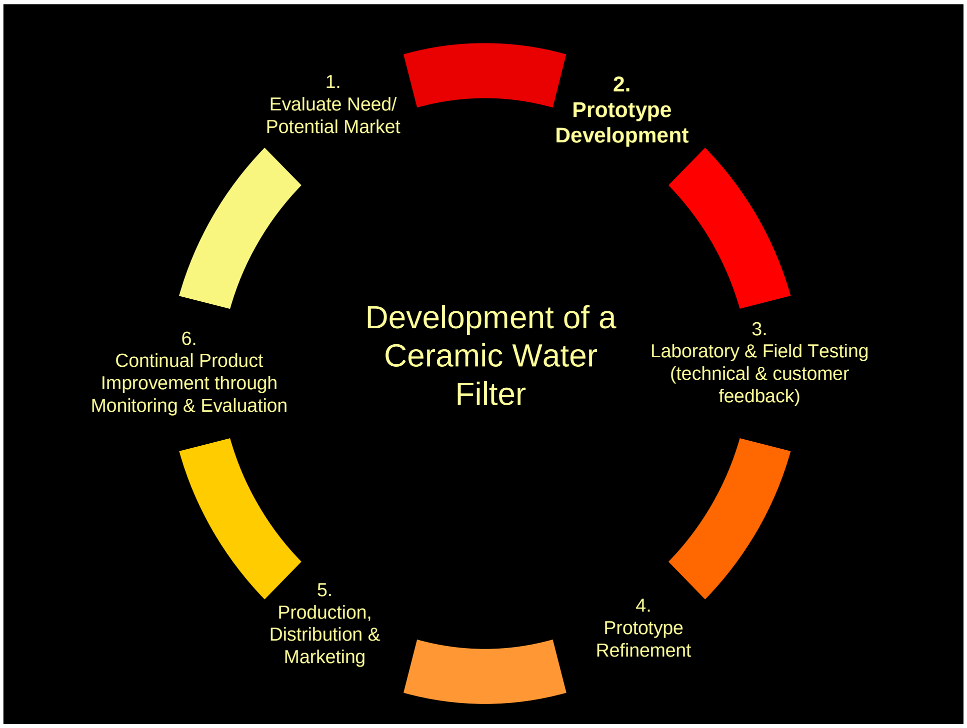


Reid Disk Filters
Microbial Removal



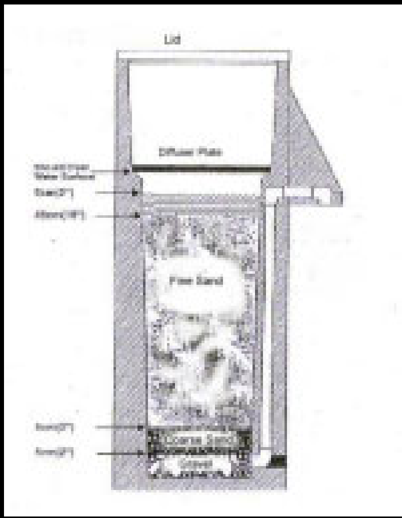

Lab Test Results
• The results from these tests support the hypothesis that colloidal silver helps to inactivate coliform bacteria – in the short term.
• A lot more lab and field testing is required
– Long term testing
– Challenge testing
– Colloidal Silver effectiveness over time


Product Marketing
• Partner with educators
• Develop a strong brand name
• Emphasize superior performance
• Marketing targeted towards women
• Seed product in schools and with persons of status
• Can a presence/absence test be used as a sales tool?



Safe Household Drinking Water via BioSand Filtration
Pilot Project Evaluation &
Feasibility Study of a BioSand Pitcher Filter
Melanie Pincus

BioSand Filter Overview



- Designed by Dr. David Manz at the University of Calgary, Alberta, Canada

- Specifically for use by poor people in developing countries.

- Relies on natural biological, chemical and physical mechanisms to purify water.

Pilot Project Evaluation

- Evaluate performance of recently installed concrete BioSand filters.

Pilot Project Potential

- Communities interested in and accepting of BioSand technology.
- All filters had high turbidity removal.
- Flow rates varied from 1.0 – 37.5 L/hr.
- Results from microbial analyses mixed (n = 9).
    - 2 filters at 99% *E. coli* removal from highly contaminated
    - raw water.
    - 3 filters contaminating relatively clean source water.

- One day of testing insufficient to adequately characterize BioSand
-filter performance. Regular, repeated samplings of source water,
-filtered water and water in collection buckets should be performed on
these household units.

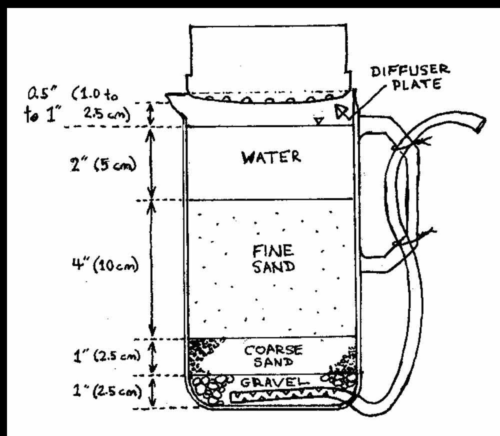
Feasibility Study of a BioSand Pitcher Filter

- Conceptualized as a smaller, cheaper alternative to the concrete BioSand filters.

- A potential interim measure as households mobilize funds for a larger capacity water filter.

- Field and laboratory experiments
to evaluate pitcher filter viability by cross-checking performance with concurrent performance of commercially available filters.

Pitcher Filter Potential



- Microbial (*E. coli*) removal of pitcher filters comparable to existing BioSand filtration technology

	Nepal	MIT
Pitcher filters	80% 86%	97% 97%
BioSand filters	81% 87%	95%
Ripening period (d)	8-10	30-40

- Strong correlation between biofilm maturation periods & source water quality.

Technical and Social Evaluation of Three Arsenic Removal Technologies in Nepal

Research Objectives

- Technical Evaluation: Arsenic removal and flow rate.
- Social Evaluation: Survey Questionnaire to evaluate arsenic awareness and social acceptability of each filter
- Economic Evaluation: willingness-to-pay

Three-Kolshi Filter

- First studied in Nepal by Jessica Hurd in 2001

2-Kolshi

First studied in Nepal

by Jeff Hwang in 2002

Arsenic-Biosand Filter

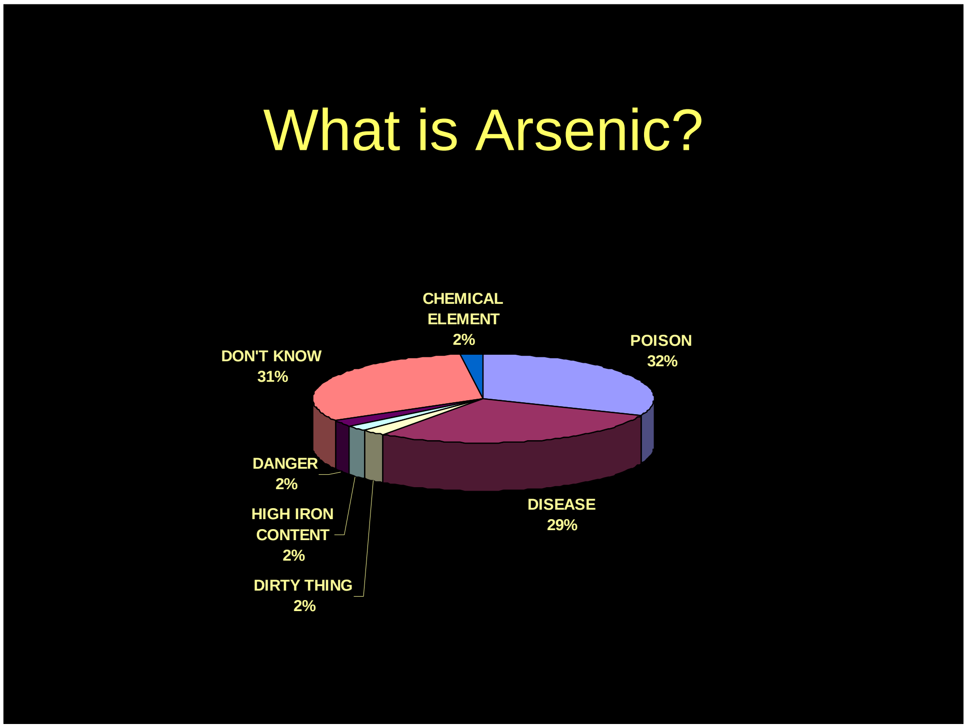
- Invented by Tommy Ngai (M.Eng.2002)
- Won Lemelson International Technology Award (2002)
- Pilot Scale implementation in Fall 2002

TECHNICAL EVALUATION

- All filters have good arsenic removal rates (>90%)
- Flow rates differ:
  - Arsenic-Biosand: 10 to 20 L/hr
  - 3-Kolshi: 0.5 to 3L/hr
- Confirmation of previous studies

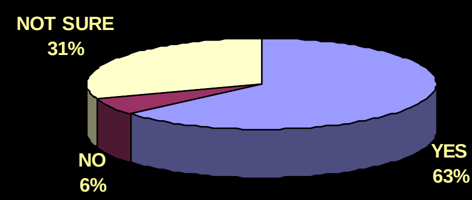
SOCIAL EVALUATION

- Surveyed 54 families
- 3 Districts
- 3 Different Technologies
- Used a survey questionnaire of 10-20 questions depending on technologies


What is Arsenic?
CHEMICAL ELEMENT 2%
POISON 32%
DON'T KNOW 31%
DANGER 2%
HIGH IRON CONTENT 2%
DIRTY THING 2%
DISEASE 29%


Are you aware of any arsenic contamination in your water?
NO 20%
YES 80%

Do you think that using the filter will protect your health?



How often do you skip filtration?

TYPE OF FILTER	SKIP FILTRATION
ARSENIC-BIOSAND	0%
THREE-KOLSHI	25%
TWO-KOLSHI	11%

CONCLUSIONS

- Good level of arsenic awareness
- Good social acceptability of each filter
- Arsenic-Biosand Filter is most appropriate.
- However, cost is above willingness-to-pay
  - If filters distributed for free or subsidized: Arsenic-Biosand is best option
  - If filters sold: 3-Kolshi for small families and Arsenic-Biosand for big families.

Semi- Continuous Solar Disinfection System

Massachusetts Institute of Technology

Xanat Flores

What is Solar Disinfection?

- Inactivation of microorganisms present in water due to:
  - UV-A radiation (λ from 315 to 400 ηm)
  - Synergistic effect with temperature
- Variations:
  - Exposure time
  - Clear, black or reflective surface

SODIS

PROS	CONS
1. Simple 2. Very cheap (almost free) 3. Easy to understand 4. Simple to maintain	1. Small amounts of water treated 2. Difficulty in getting bottles (problem in Lumbini) 3. Waste management of empty bottles 4. Social acceptability (hard work for housekeepers)

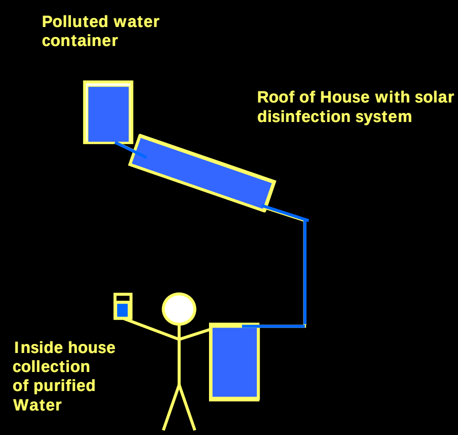
CONTINUOUS SOLAR DISINFECTION SYSTEMS

PROS	CONS
1. Larger quantities of water purified in a given time.	1. More difficult to maintain and operate. 2. More expensive. 3. Requires more sophisticated operator

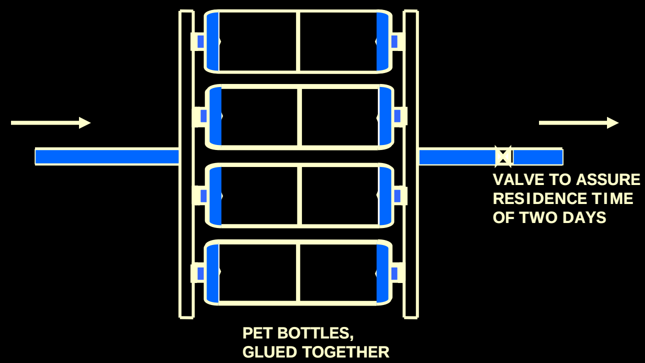
SEMI-CONTINUOUS SODIS

PROS	CONS
1. Larger amounts of water treated. 2. Inexpensive 3. PET bottles are not replaced as often as in SODIS. 4. Relatively simple to maintain and operate	1. Mechanism needs to be very well understood. 2. Flow rates have to be established for different weather conditions.

SEMI-CONTINUOUS SODIS



SEMI-CONTINUOUS SODIS



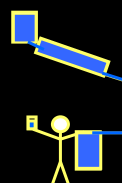
OBJECTIVES OF MY RESEARCH

- Technical feasibility of SC-SODIS system
  - Construction
  - Performance
  - Use of local materials.
- Social acceptability
- Economic feasibility

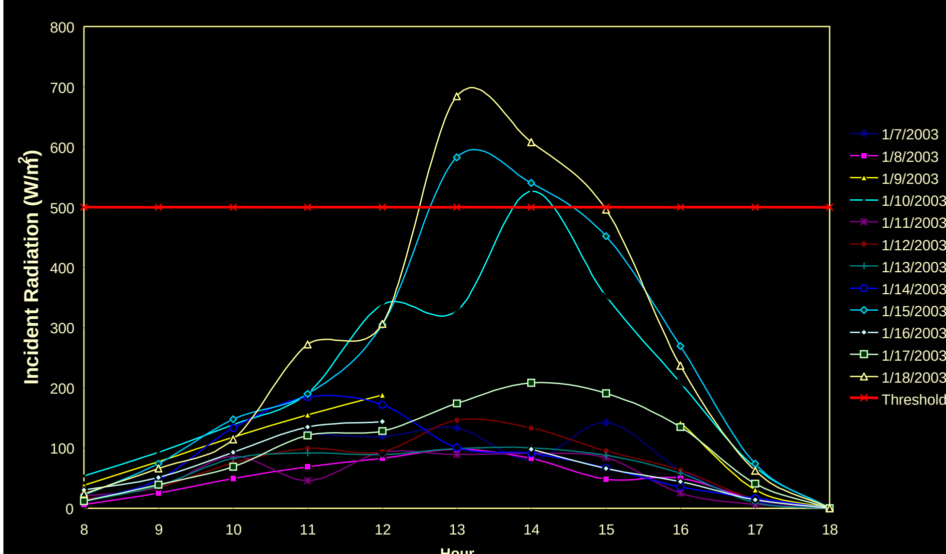
Constructed System

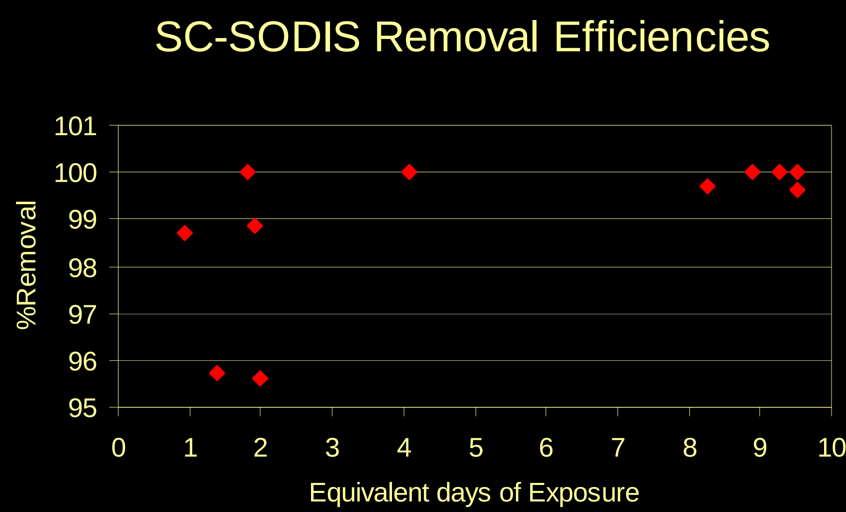
RESULTS

SC-SODIS



Solar Radiation Results





DIFFICULTIES FOUND

- Lack of E. coli due to extreme cold.
- Finding the “right” materials.
- Three week study -- limited data set and many variables:
  - Solar radiation
  - Flow rate
  - Concentration of pollutants

CONCLUSIONS

- Technical: SC-SODIS is technically feasible in region studied based on data collected.
- Construction: Found local materials (Butwal and Lumbini).
- Social: Preliminary feedback showed local people preferred SC-SODIS to SODIS.
- Economic: Construction costs below $0.50 (NRs 300).

RECOMMENDATIONS

- Find a local manufacturer of SC-SODIS system to reduce construction time.
- Further study of flow rates.
- Study during monsoon season.

Nepali Wastewater Solutions

The Effects of Carpet Dye on the Bagmati River

Hillary Green

Effects of Detergent Use on Water Quality in Kathmandu, Nepal

Amanda Richards

Assessment of Constructed Wetland System in Nepal

Saik-Choon Poh

Wastewater Situation In Nepal

Introduction

- Surface water pollution is one of the most serious environmental problems in Nepal
- Wastewater treatment plants almost non-existent
- Hardly any action taken towards WW treatment by the Nepalese government

Wastewater from Kathmandu

- **Domestic Wastewater**
  - Population (year 2000) : 1.43 million
  - Wastewater Generated: 124 MLD
  - Sewerage System Coverage: 38%
  - Wastewater Collected: 47 MLD
- 5 municipal wastewater treatment plants
  - Total Treatment Capacity (year 2000) : 19.9 MLD
  - Capacity Deficit : -27.1 MLD

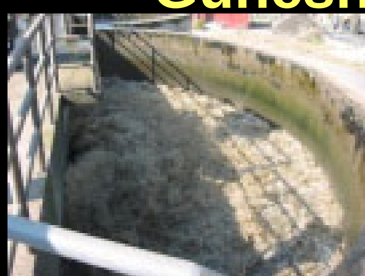
(ADB TA Number 2998-NEP, Feb. 2000)

Overview of Wastewater Treatment Plants

Plant	Reported Capacity MLD	Status	
		ADB Feb.2000 Report	MIT Nepal Team Jan. 2003
Guheshwori	17.3	Under Construction	Operating
Hanumanghat	0.5	Partially operating	Not operating
Sallaghari	2.0	Partially operating	Not operating
Kodku	1.1	Partially operating	Partially operating
Dhobighat	15.4	Not operating	Not operating

(Arata, 2003)

Guheshwori WWTP

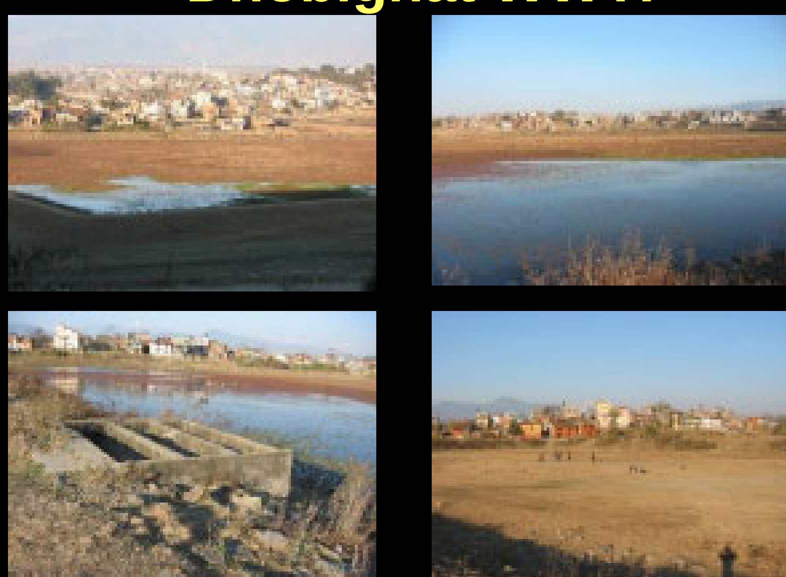



Hanumanghat WWTP

Sallaghari WWTP

Kodku WWTP

Dhobighat WWTP



Carpet Dye in Nepali Surface Water

Hillary Green

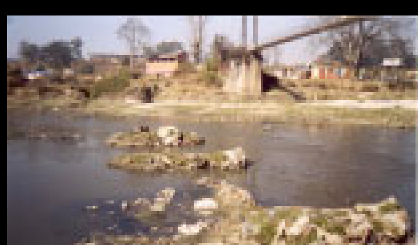
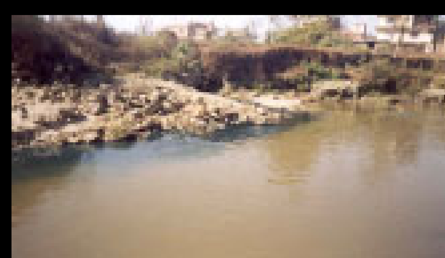
Carpet Industry in Nepal

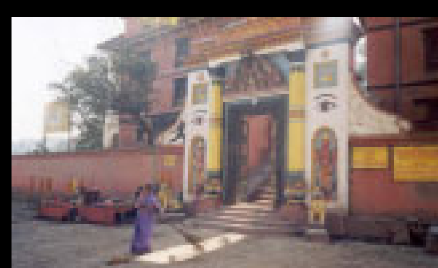
- One of Kathmandu Valley's largest industries (50 carpet manufacturers)
- Dye wastewater often sent directly to rivers
- Synthetic dyes are usually preferred over natural dyes
- Most synthetic carpet dyes contain chromium, copper or cobalt

Do Carpet Dyes Cause Significant Water Quality Deterioration of the Bagmati River ?

- Identify sites of carpet manufacturers along the Bagmati
- Test and collect relevant water quality data
  - absorbance
  - chromium
  - COD
  - DO

Sampling Points Along the Bagmati



Chromium Results - Water Samples

- Out of 12 water samples, 8 had chromium levels <0.01 mg/L
- The other levels were as follows

Sample Location	Cr Concentration (mg/L)
Pashupatinath	0.01
Tilganga	0.03
Sundarighat	0.02
Chovar	0.03

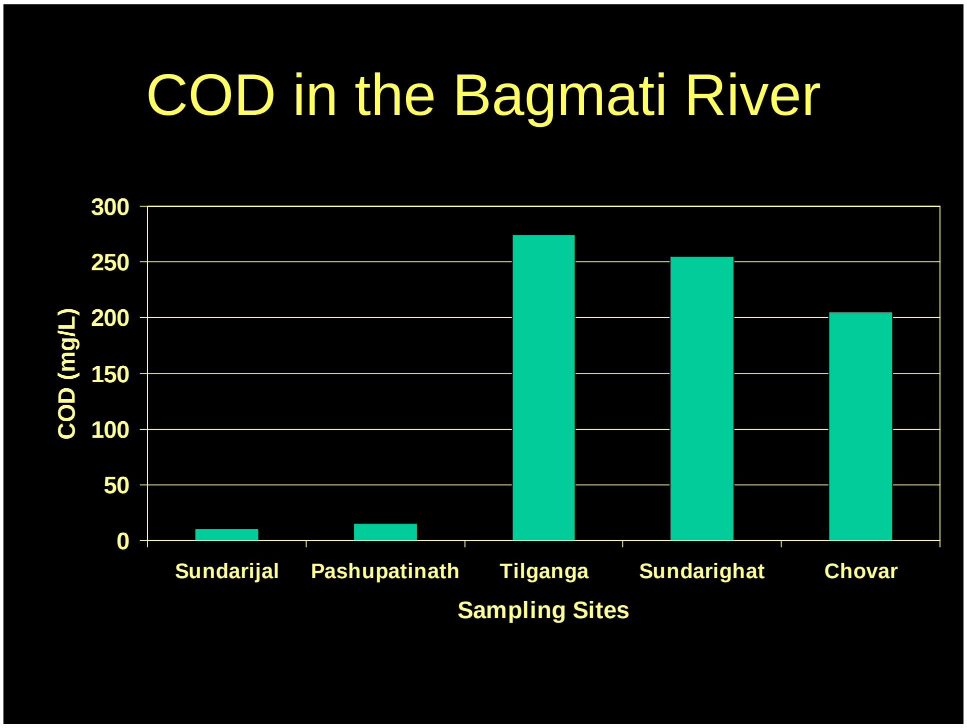
- WHO guideline for chromium in drinking water is 0.05mg/L

Chromium Results - Dye Samples

- Dye samples acquired from Mount Everest Dying Company
- Chromium levels in dyes as follows

Dye Color	Cr Concentration (ppm)
Indigo	55.3
Red	1,270
Navy	2,400
Black	2,400

- An increase in dye waste to the river could increase the Cr levels in the river



Conclusion

- Decreasing dye waste to the Bagmati river will help decrease COD levels in the river
- Presence of color does not necessarily mean presence of chromium and vice versa
- Further studies needed to determine possible chromium problems

Effects of Detergent Use on Water Quality in Kathmandu, Nepal

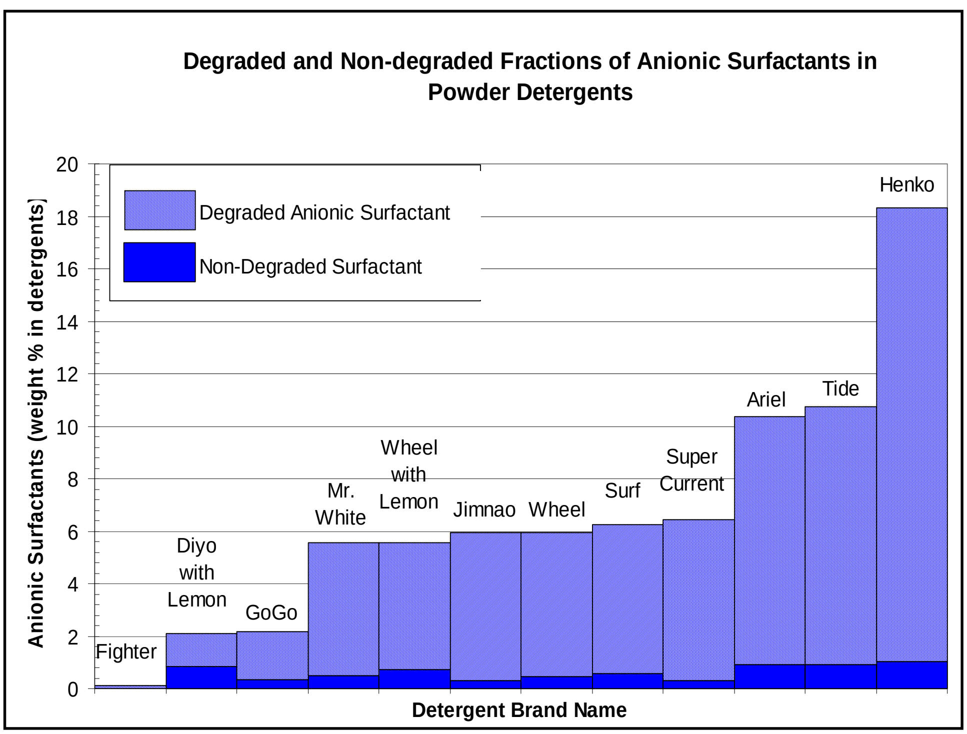
Amanda Richards

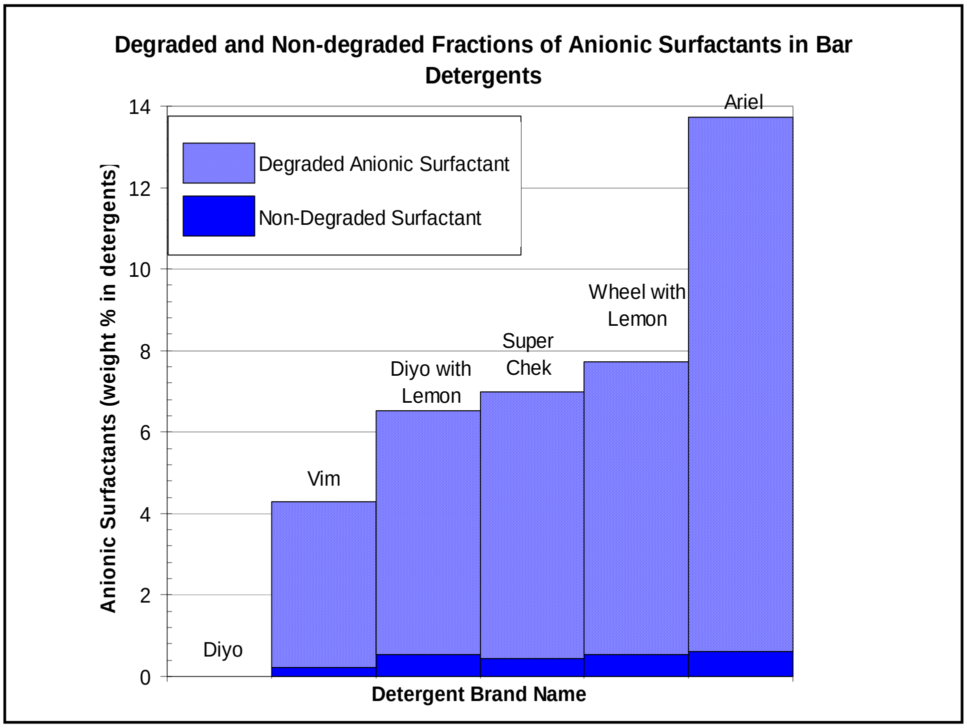
Overview of Guheshwori WWTP

- Only operating municipal WWTP in Nepal
- Activated sludge process with 17.3 MLD capacity
- Foaming problem in aeration tanks, location of oxygen supply
- Possible culprits:
  - Filamentous bacteria
  - Anionic surfactants in synthetic detergents

Surfactant Analysis

- Two classifications of anionic surfactants:
  - Very slowly degraded, causes foaming problems (ABS)
  - Easily biodegraded, no foaming problems (LAS)
- Surfactant Analysis
  - 19 laundry detergents collected from Nepal
  - Test for total anionic surfactants
  - Monitor surfactant degradation with time
  - Remaining surfactant considered to be ABS





Surfactant Analysis, Continued

- Estimate detergent effects:
  - Instructions suggest 1 handful detergent/half-bucket water
  - Approximately 25 g detergent/4 L water (6.25 g/L)
  - With persistent surfactant levels of 5 mg/g detergent, estimate **32 mg ABS/L** wash water
- ABS foaming limit is **~0.5 mg ABS/L** water
- Difficult to estimate the frequency of household laundry washing (# loads/family-wk)
  - Analysis done assuming 1 load/family-wk, 5 loads/family-wk and 10 loads/family-wk

Surfactant Conclusions

- Laundry detergent not a likely major contributor to foaming at Guheshwori WWTP
  - Probable dilution to concentrations below foaming limit
  - Detergent biodegradability meets standards set by United States and European Governments
- Other possible causes of foaming for future study:
  - Surfactants used in industrial detergents (textile and carpet industries)
  - Filamentous bacteria

Phosphates Analysis

- Detergents analyzed for phosphates
  - Evaluate contribution to eutrophication in the Bagmati River
- Average concentration of 402 mg PO_4/kg detergent, or **2.5 mg PO_4/L wash water**
- PO_4 levels from washing laundry are insignificant compared to Bagmati River concentrations (reach as high as **1.6 mg/L**)
  - Analyzed at 1, 5 and 10 loads/family-wk

Assessment of Constructed Wetland Systems in Nepal

Saik-Choon Poh

Constructed Wetland Systems in Nepal

- Reasons for failure of large treatment plants:
  - High Cost
  - Inefficient gov't water/ WW bureaucracy
  - Inappropriate transfer of 1st World technology to 3rd World conditions
- Small and decentralized treatment plants are high in demand
- Constructed Wetlands introduced in Nepal in 1997 by a local NGO research institute, ENPHO, as a cheap alternative (Laber, Haberl, Shrestha 1999)

Constructed Wetlands (CW)

Types (CW):

- Free Water Surface
- Vegetated Submerged Bed

In Kathmandu, Nepal:

- 5 existing CW
- Sub-surface
- Combination of Horizontal Vertical Flow Bed

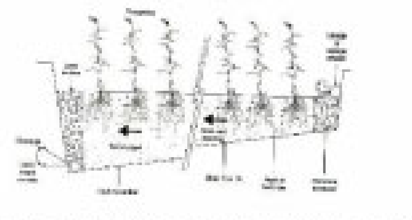


Figure 1: Typical Cross-Section of Horizontal Flow of Constructed Wetlands

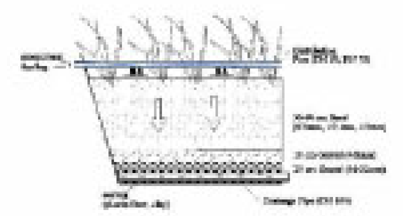


Figure 2: Typical Cross-Section of Vertical Flow Constructed Wetlands

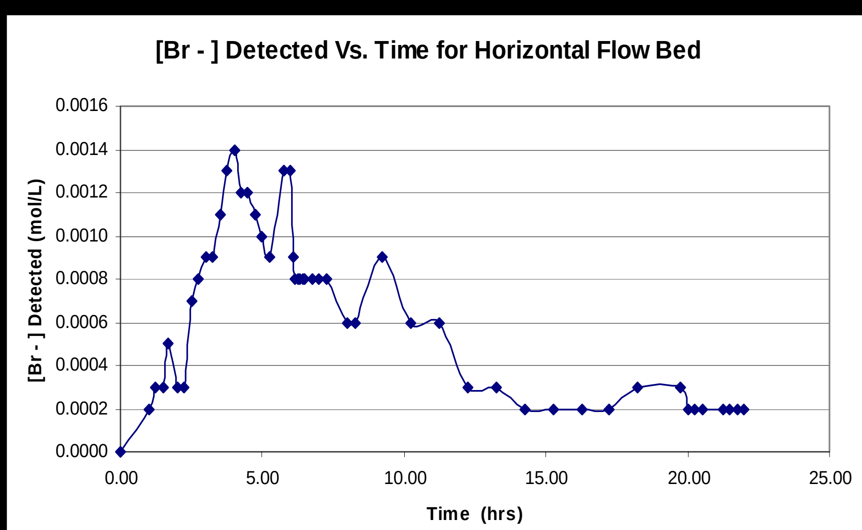
Existing CW Systems in Nepal

No	Project	Types of Constructed Wetlands
1	Dhulikhel Hospital	Horizontal & Vertical Flow Bed
2	Grey Water Recycling	Vertical Flow Bed
3	Septage Treatment for Kathmandu Municipal Corporation	Vertical Flow Bed
4	Malpi International School	Horizontal & Vertical Flow Bed
5	Sushma Koirala Memorial & Reconstructive Surgery Hospital	Horizontal & Vertical Flow Bed

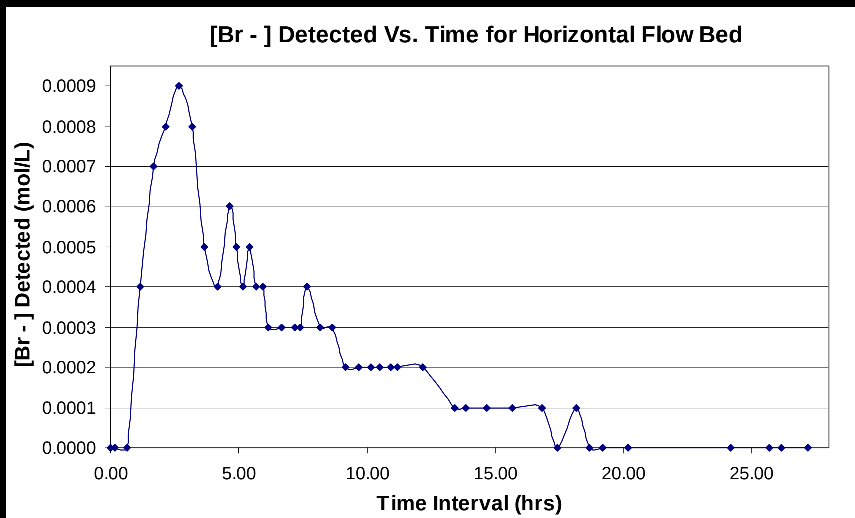
Project Objective

- Investigate the treatment efficiency through hydraulic studies
- Determine the water retention time in the wetland bed (Bromide as Tracer)

SKM Hospital (HFB)



Dhulikhel Hospital (HFB)



Theoretical Background

Residence Time Distribution Function:

$$RTD(t) = \frac{QC(t)}{\int_0^\infty QC(t)dt}$$

Detention Time:

$$T_{det} = \int_0^\infty tRTD(t)dt$$

Detention Time

Sushma Koirala Memorial Plastic & Reconstructive Surgery Hospital

Detention Time For Horizontal Flow Bed			*Detention Time For Vertical Flow Bed*		
Constant Q T-Rule	8.6	hrs	*Constant Q T-Rule*	10.1	hrs
With Q facor	6.7	hrs	*With Q factor*	7.8	hrs

Dhulikhel Hospital

Detention Time For Horizontal Flow Bed			*Detention Time For Vertical Flow Bed*		
Constant Q T-Rule	6.3	hrs	*Constant Q T-Rule*	11.0	hrs
With Q facor	5.6	hrs	*With Q facor*	12.2	hrs

Theoretical Background

Reaction in CW modeled as 1st Order reaction:

$$\frac{C(t)}{C_o} = \exp(-k_r t)$$

Average Concentration of Pollutant Remained in CW:

$$\frac{\overline{C_e}}{C_o} = \int_0^{\infty} RTD(t)\exp(k_r t)dt$$

K_r Value vs. %Removal Efficiency

Dhulikhel Hospital

K_r For Horizontal Flow Bed

k_r (1/day)	10.0	12.2	15.0	17.5	22.5	35.0	50.0
R.E (%)	80.0	84.8	88.3	90.7	94.0	97.6	99.0

K_r For Vertical Flow Bed

k_r (1/day)	5.0	7.0	9.0	11.0	13.0	20.0	25.0
R.E (%)	84.0	89.5	92.5	94.5	95.8	98.1	98.9

Sushma Koirala Memorial Plastic & Reconstructive Surgery Hospital

K_r For Horizontal Flow Bed

k_r (1/day)	9.0	11.0	14.0	17.0	20.0	28.0	45.0
R.E (%)	81.5	86.0	90.5	93.2	95.0	97.4	98.9

K_r For Vertical Flow Bed

k_r (1/day)	7.0	8.0	10.0	12.0	17.0	22.0	25.0
R.E (%)	80.5	83.8	88.7	92.0	96.4	98.3	98.9

Summary of CW's Performance

Dhulikhel Hospital

Date	Parameters											
	BOD(mg/l)			COD(mg/l)			TSS(mg/l)			PO4(mg/l)		
	In	Out	% Removal	In	Out	% Removal	In	Out	% Removal	In	Out	% Removal
12-Jul-02	62	2	98	122	20	84	66	3	95	3	4	-
24-Sep-02	84	5	94	131	23	82	106	5	95	4	1	75
15-Nov-02	72	2	97	98	22	78	46	5	89	3	2	45
14-Jan-03	349	14	96	680	50	93	380	25	94	9	5	43
Average Removal %			96			84			93			54

(ENPHO, 2003)

Summary of CW's Performance

SKM Hospital

Date	Parameters											
	BOD_5 (mg/l)			COD (mg/l)			TSS (mg/l)			NH3(mg/l)		
	In	Out	% R	In	Out	% R	In	Out	% R	In	Out	% R
37043	436	18	96	1746	71	96	225	8	96	148	26	82
37159	737	5	99	1416	71	95	520	5	99	131	1	99
37445	212	2	99	433	20	95	160	3	98	111	2	98
37512	475	23	95	1110	83	93	655	6	99	26	1	97
37577	279	3	99	766	40	95	146	10	93	45	3	94
Elimination Rates %			**98**			**95**			**97**			**94**

(ENPHO, 2003)

Conclusions

- Treatment performance of CW is good
- More accurate determination of Kr value and detention time will enable even better performance and improved design in future
- CW has a high potential to address wastewater treatment needs in Nepal

Questions ?

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References

Arata, Tetsuji. *Wastewater in the Greater Kathmandu*. Japan Association of Environment and Society for the 21st Century 2003

Laber, Johannes; Haberl, Raimund; Shrestha, Roshan R. *Two-Stage Constructed Wetland for Treating Hospital Wastewater in Nepal*. Wat. Sci. Tech, Vol. 40, No.3, pp. 317-324, 1999. Elsevier Science Ltd: Great Britain. 1999.

Metcalf & Eddy, Inc. with CEMAT Consultants, Ltd; *ADB TA Number 2998 – NEP*, "Urban Water Supply Reforms in the Kathmandu Valley", Volume 1, February 18, 2000.

Shah, Ram Deep and Das Sunil Kumar. "Performance of Deep Oxidation Ditch", 28th WEDC Conference, 2002.

Shrestha, Roshan R.. *A New Step Towards Wastewater Treatment in Nepal*. A Journal of the Environment, Vol. 6, No.7, 2001. Ministry of Population and Environment, Nepal. 2001

WHO, 2000.