Water Supply Options in Arsenic-Affected Regions of Cambodia: Targeting the Bottom Billion

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Motivation for this work

“A Study of Options for Safe Water Access in Arsenic Affected Communities in Cambodia”
(WSP/Shantz, 2012)

- Continue to promote household (HH) drinking water treatment and safe storage – biological contaminants
- For arsenic avoidance:
  - Large-scale piped water systems
  - Rainwater harvesting
  - Vendor sale and delivery
- Design interventions to reach the poorest or marginalized

Objectives

- Compare costs of providing water using six arsenic mitigation options:
  - Conventional arsenic-avoidance (5)
  - Innovative arsenic-removal filtration media (1)
- Evaluate costs with willingness-to-pay
- Present a "need-to-reach" cost level for optimal mitigation of arsenic
  - lowest three income quintiles (Q3, Q4, Q5)
- Present an optimization scheme for rural water supply in Cambodia

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Water Technologies for Emerging Regions
"Water and Sanitation for All"

(2) purchase from private water vendor

(1) harvest and storage of rainwater

(3) piped network water supply

(6) arsenic adsorption from well water using innovative materials

(4) shallow, hand-dug well

(5) new tubewell to arsenic-free aquifer

Rainwater storage

Stacked rings, ~400 liters per ring

Traditional pieng jar, ~500 liters

Spherical tank (RDI), ~4000 liters

Rainwater costs

- Capital costs:
  - Pieng jar
    - ~500 liters capacity
    - $15-20
    - Lifetime: 20 years
  - Resource Development International (RDI) spherical vessels
    - 4000 liters capacity
    - $160
    - Lifetime: 20 years

- Operating costs:
  - Water – free!
  - Some minor repairs – cracks, leaks (~ $5 per year)

Sources: WSP 2012; field surveys 2012

Vendor supply

- Seasonal, dependent upon surface water (ponds, rivers)
- Not universally available
- ~$2 / 1000 liters of water delivered
- Not treated

Sources: WSP 2012; field surveys 2012

Piped Network Operators (PNOs)

- Rural: 4-6% of population
- Water often not treated
- Charge based on actual consumption
- 7 days/wk; limited hours

- One-time connection fee ($34 - $97)
- Water tariff / usage fee ($0.14 - $0.37 / m^3)

Sources: World Bank 2000, 2009; WSP 2012; Visal 2011

Hand-dug well

- Large-diameter, shallow (2-18 meters depth)
- Just below water table (built in dry season)
- Potential for surface contamination
- Presented as arsenic-safe, but no guarantees!

Hand-dug well under construction

Source: Ravenscroft 2009

Replacement tubewell

- Drilled to different depth or location for reduced arsenic
- Reliance on driller's well logs
  - Set screen at appropriate depth

Source: Ravenscroft 2009

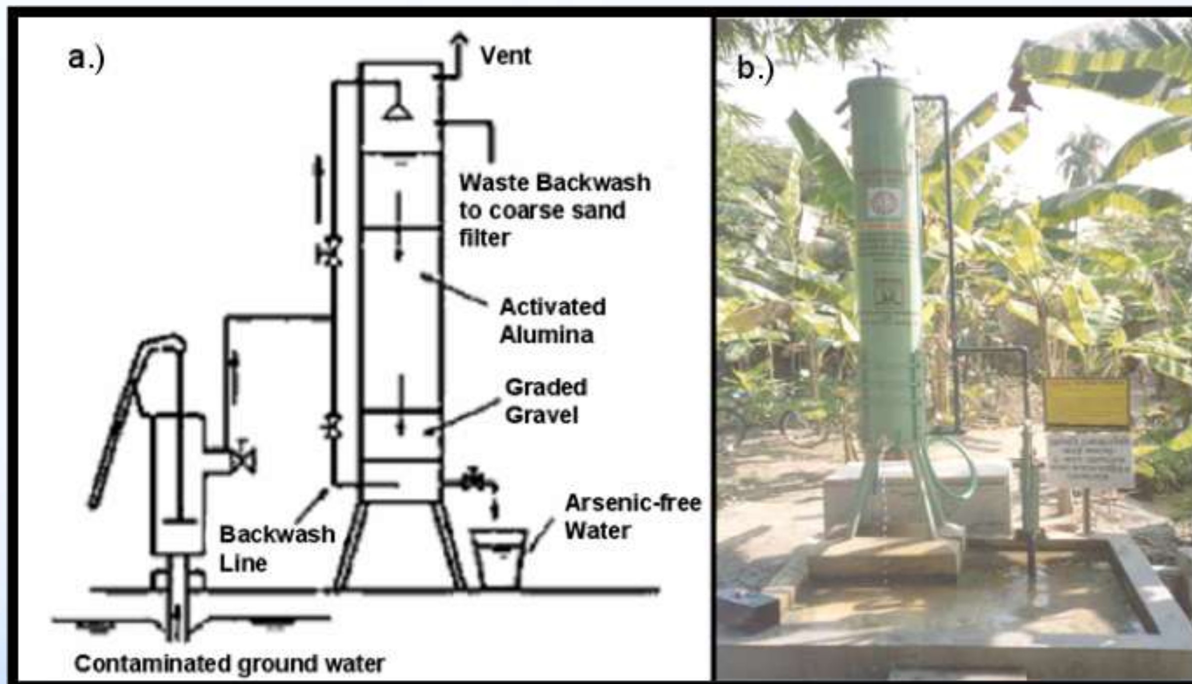
Arsenic-removal using adsorptive media

Typical media:

- Activated alumina
- Iron-oxide coated sand
- Granular ferric hydroxide
- Synthetic (proprietary)

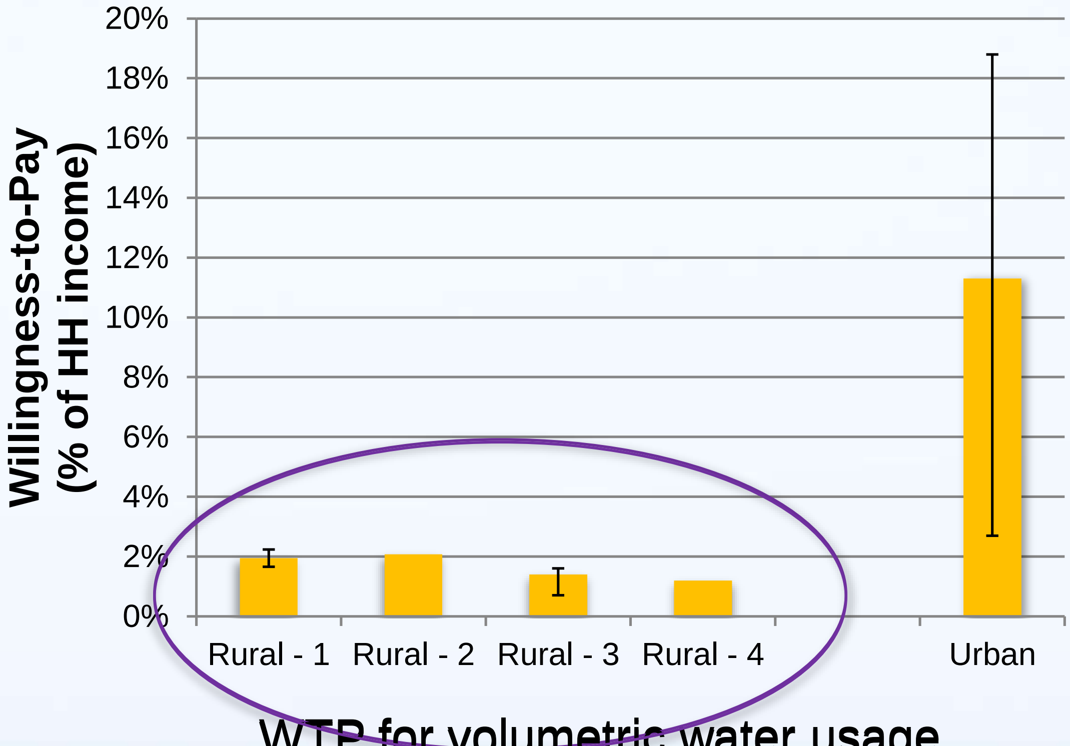
Emerging media:

- Iron-amended rice husk char
- Iron-amended rubber tree char



Source: Sarkar, et al. 2005

Results - Willingness-to-Pay



WTP for volumetric water usage
as percentage of HH income
(5 studies – Cambodia, Nigeria, Ethiopia, Bangladesh)

- **Four independent studies agree on range of WTP in rural settings**

Sources: WSP 2012, Visal 2010, Whittington, 1991
Wendimu 2011, WSP 2003

Arsenic-removal via adsorption

Filter change-out (days) =

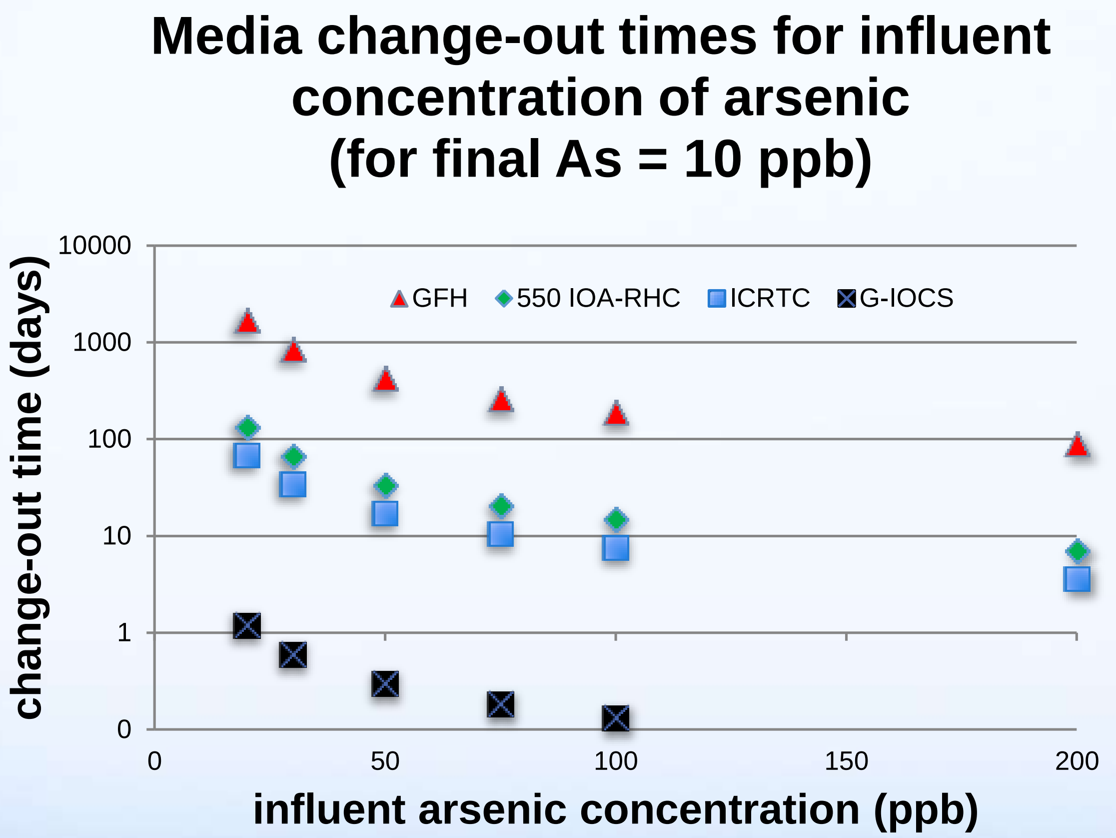
$$\frac{[\text{Mass (g)} * Q_e \text{ (mg As/g)}]}{[\text{Pop (cap)} * \text{consumption (L/da-cap)} * (C_{in} - C_t) \text{ mg/L}]}$$

Q_e = filter effectiveness (mg As/g media)
C_{in} = input concentration of As (mg/L)
C_t = equilibrium (final) concentration of As (mg/L)

Assumptions =

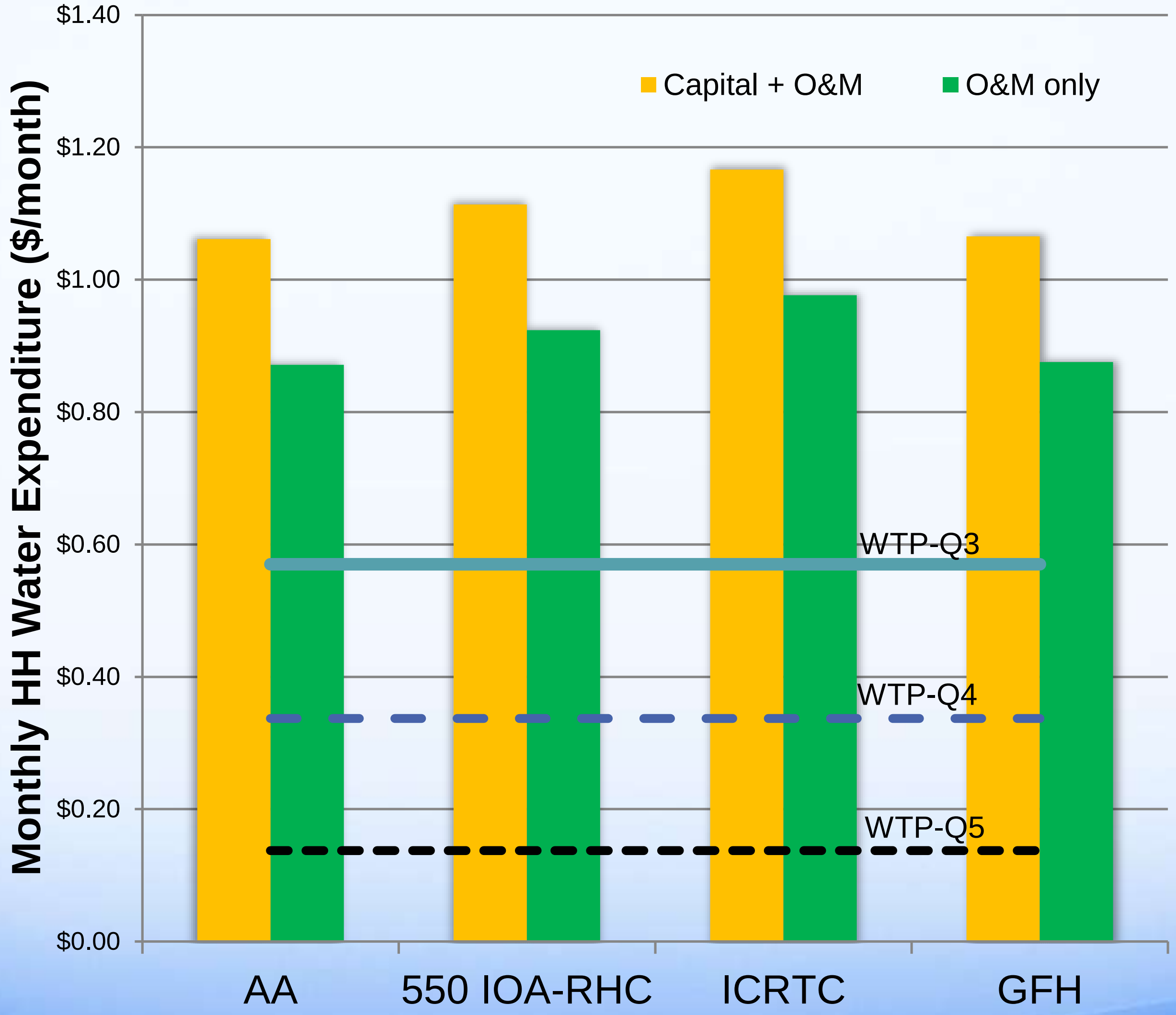
consumption = 10 lpcd
HH size = 5 persons
village size = 500 persons (100 households)

Range of media effectiveness



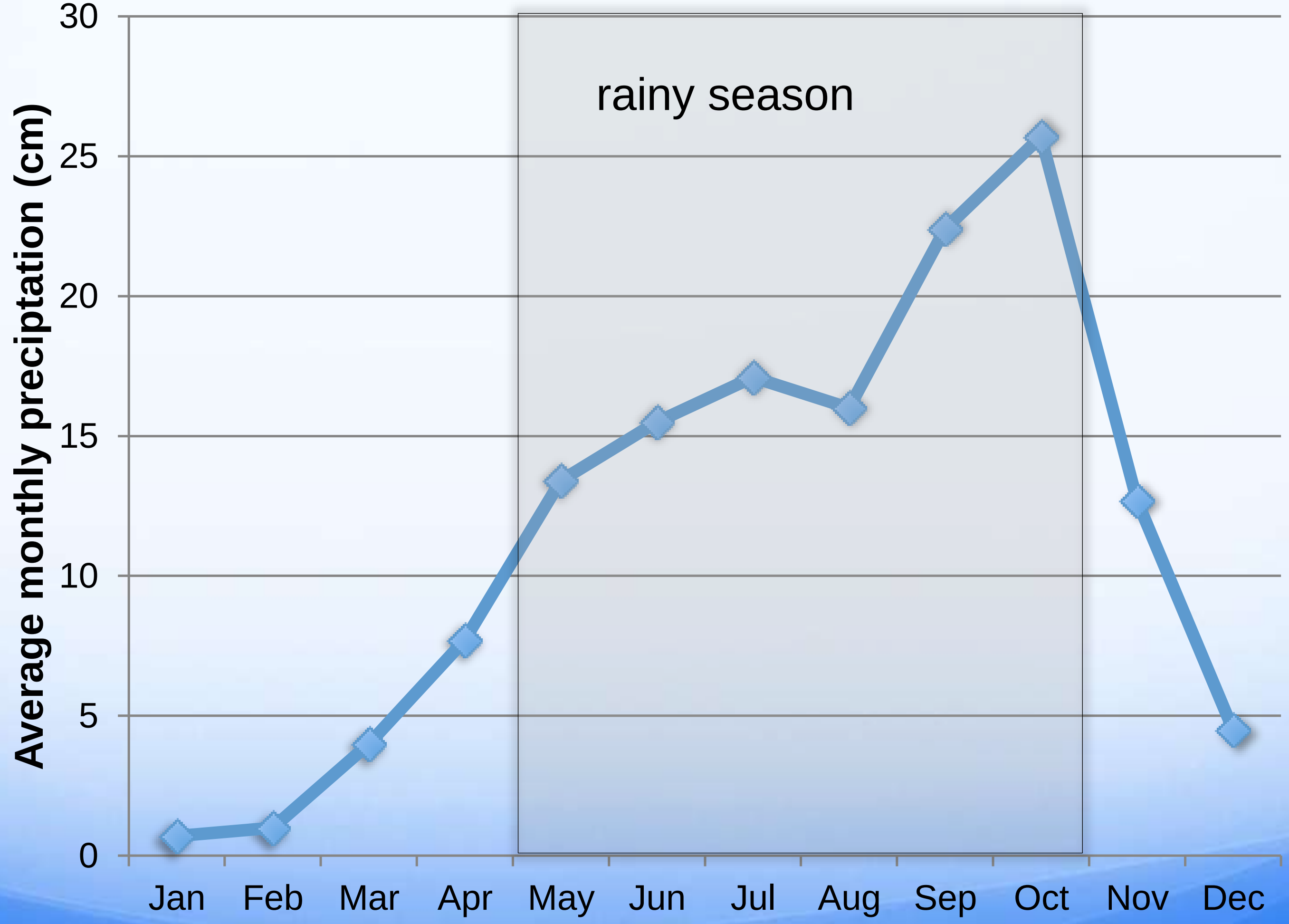
GFH = granular ferric hydroxide (Badruzzaman, 2004)
550 IOA-RHC = iron-oxide amended rice husk char (Cope, 2012)
ICRTC = iron-coated rubber tree char (Webster, 2011)
G-IOCS = goethite iron-oxide coated sand (Mlilo, 2010)

“Need-to-reach” costs for adsorption

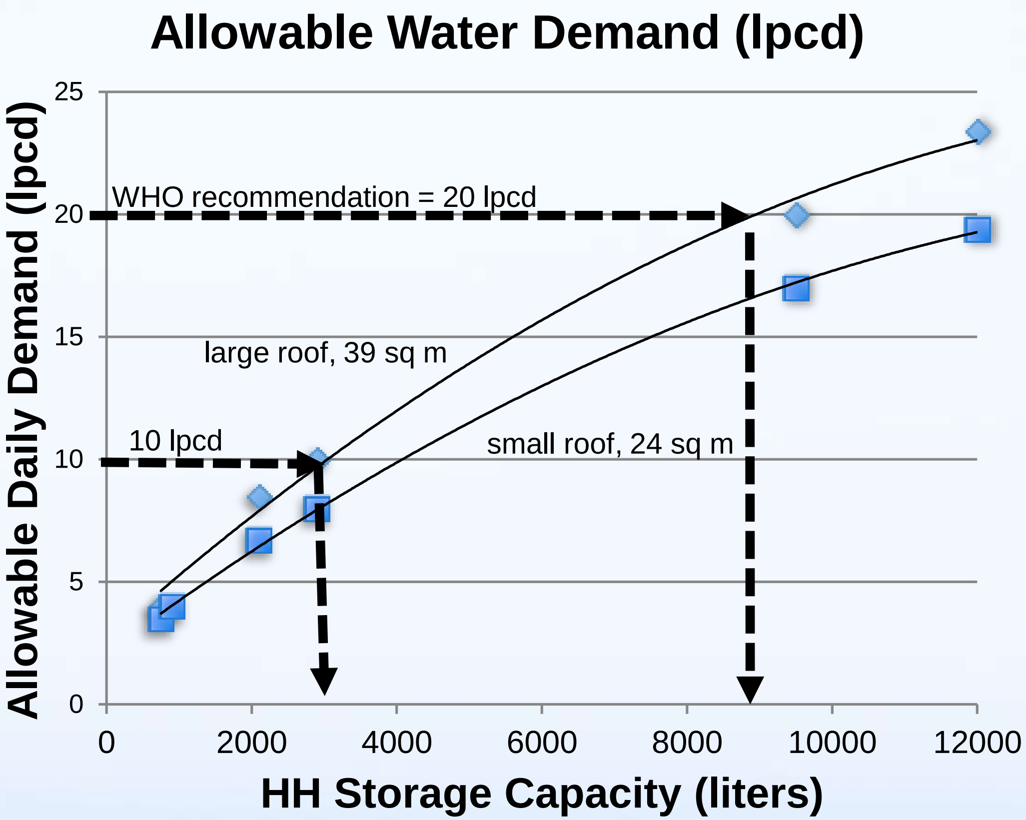


Influent / Effluent As concentration = 200 / 10 ppb
System lifetime = 20 years; *i* = 5%; 100 HHs served, ~10 lpcd

Cambodian Rainfall



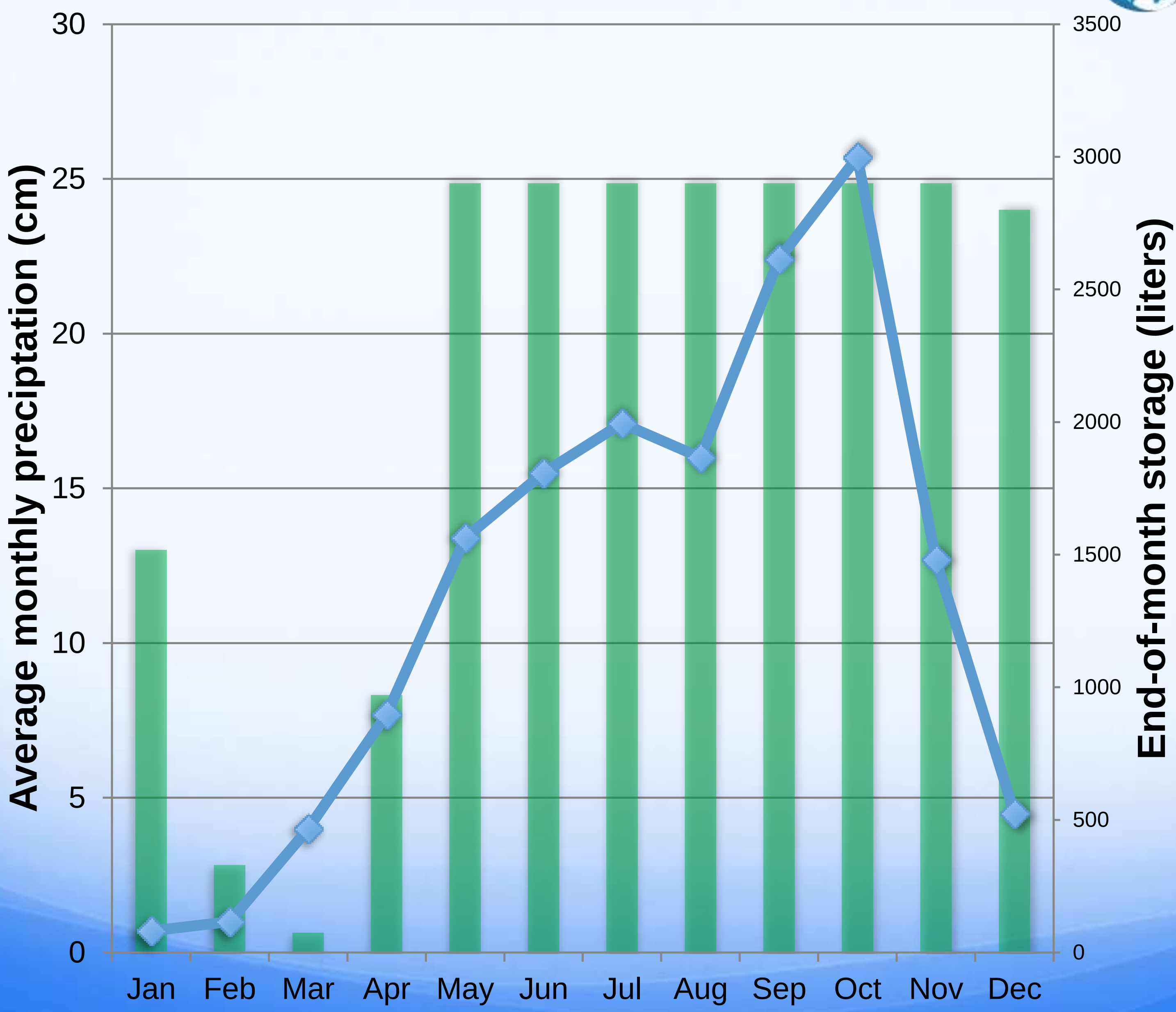
How much storage is needed?



$V_t = V_{t-1}$ + rainfall collection – demand

Provision is made for minimum of 40 liters at end of each month; based on family of 5; collection efficiency = 80%

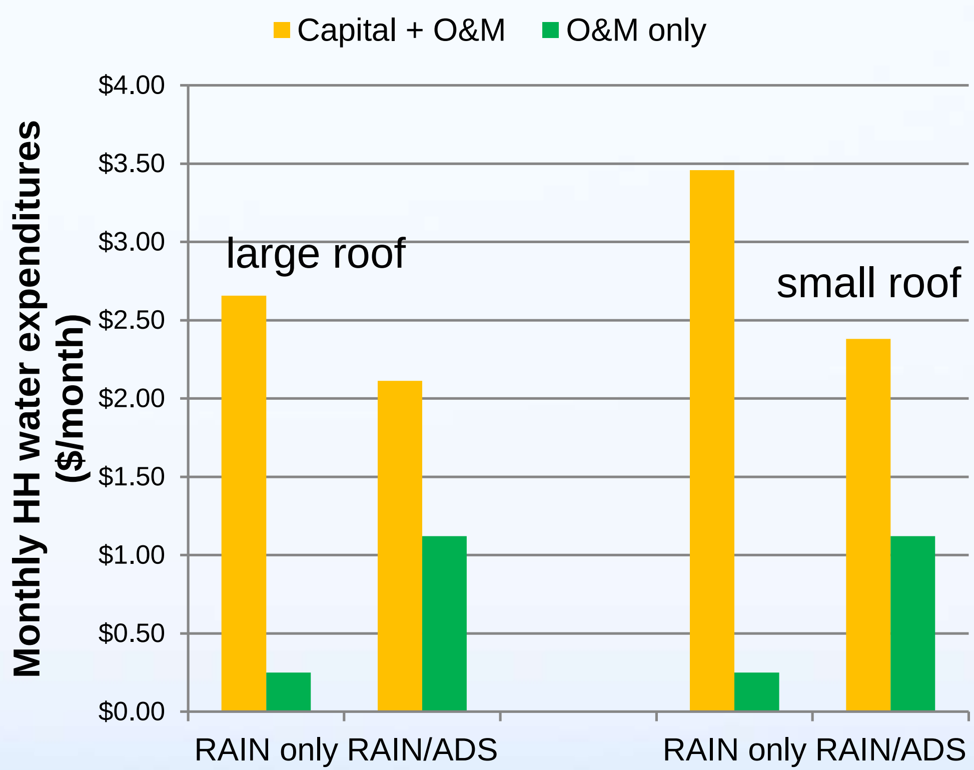
Example: 2900 liters of storage / 10 lpcd / large roof



Optimization of Arsenic Mitigation

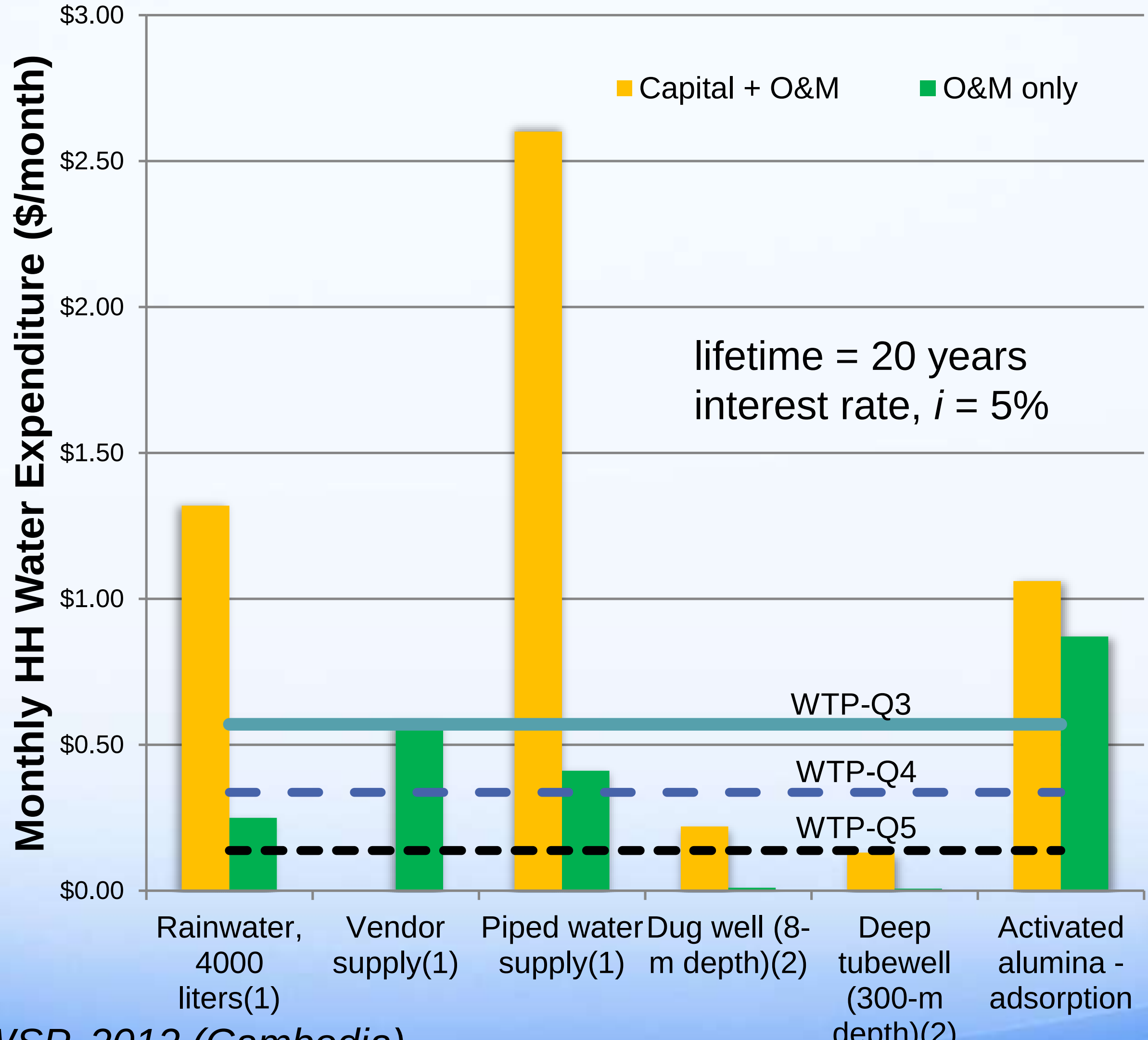
- Rainwater harvest only
  - Large roof, 20 lpcd
  - Small roof, 20 lpcd
- Rainwater + Wellwater treated by arsenic adsorption (reduction of 200 to 10 ppb)
  - Large roof (10 lpcd) + treated wellwater (10 lpcd)
  - Small roof (10 lpcd) + treated wellwater (10 lpcd)

Optimization



A hybrid system (rainwater + adsorption) reduces amortized capital costs but increases monthly O&M

Amortized Monthly Costs for Water



(1) Shantz/WSP, 2012 (Cambodia)

(2) Ahmed/World Bank, 2005 (India/Bangladesh)

Findings and Future work

- Affordability - Subsidies for capital costs; water tariffs covering annual O&M costs
- Willingness-to-Pay - a useful surrogate as a “target goal” to reach for novel and emerging water treatment
- Current efficiencies and production of adsorptive media need to become more cost-effective in order to reach the lowest income quintiles in Cambodia
  - Economies of scale needed
- A combination of rainwater harvesting and As-adsorption may provide an optimal system by dampening capital costs (but increases O&M cost)
- Future work:
  - explore further combinations of avoidance and treatment systems
  - examine ways in which As-adsorption can reach next lowest quintile

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