Fundamentals of Asset Management

Step 2. Assess Performance, Failure Modes

A Hands-On Approach

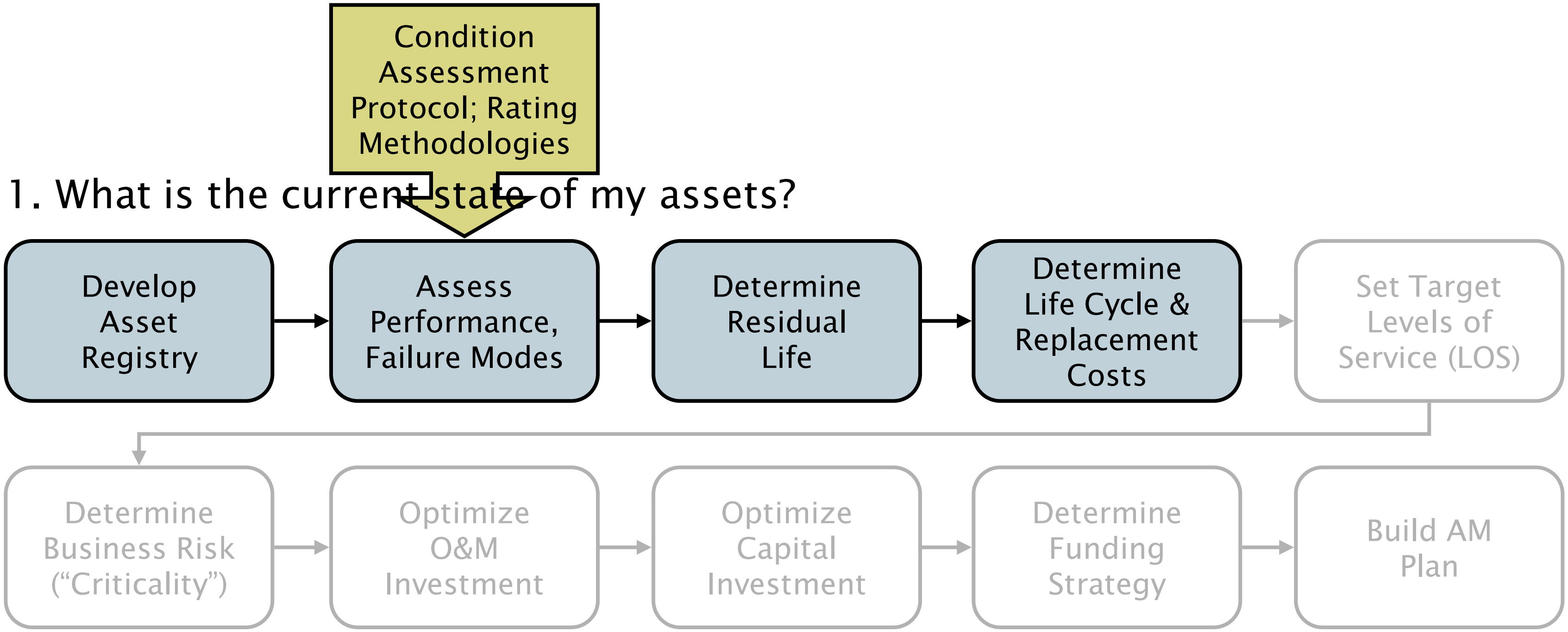
Tom’s bad day…

First of 5 core questions, continued

1. What is the performance of my assets?
   - *Why* should we assess condition and performance?
   - *How* do we assess condition and performance?
   - What are the *four major failure modes*?

AM plan 10-step process

1. What is the current state of my assets?



Our objective: to manage sustained performance

- What do we mean by “performance”?
  - Asset functionality
  - Level of service
  - Availability
  - “Maintainability / sustainability”
  - Reliability
- Common “proxies” for performance
  - Condition
  - Age
  - Usage

Fundamental principle of condition assessment

Condition assessment is important only to the extent it provides insight into…

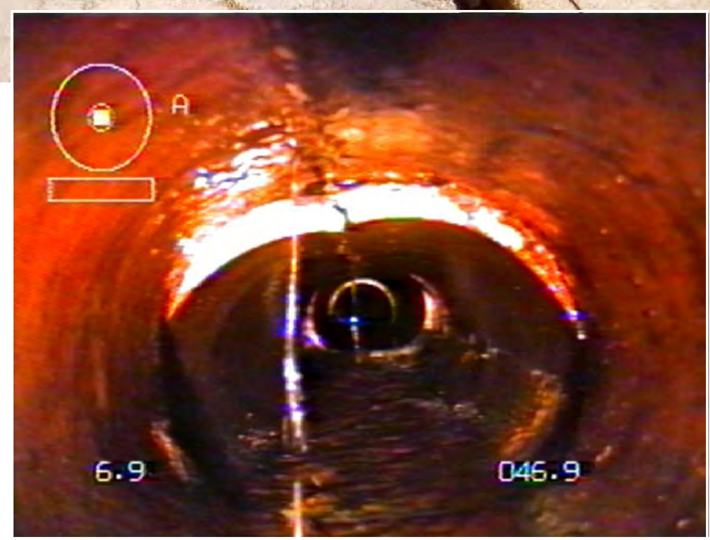
- *Nature* of possible failure
  - Root cause
  - Pattern (shape of the deterioration curve)
- *Timing* of possible failure (residual functional life)

Typical condition assessment techniques

- Visual inspection
- Non-destructive testing
- Destructive testing

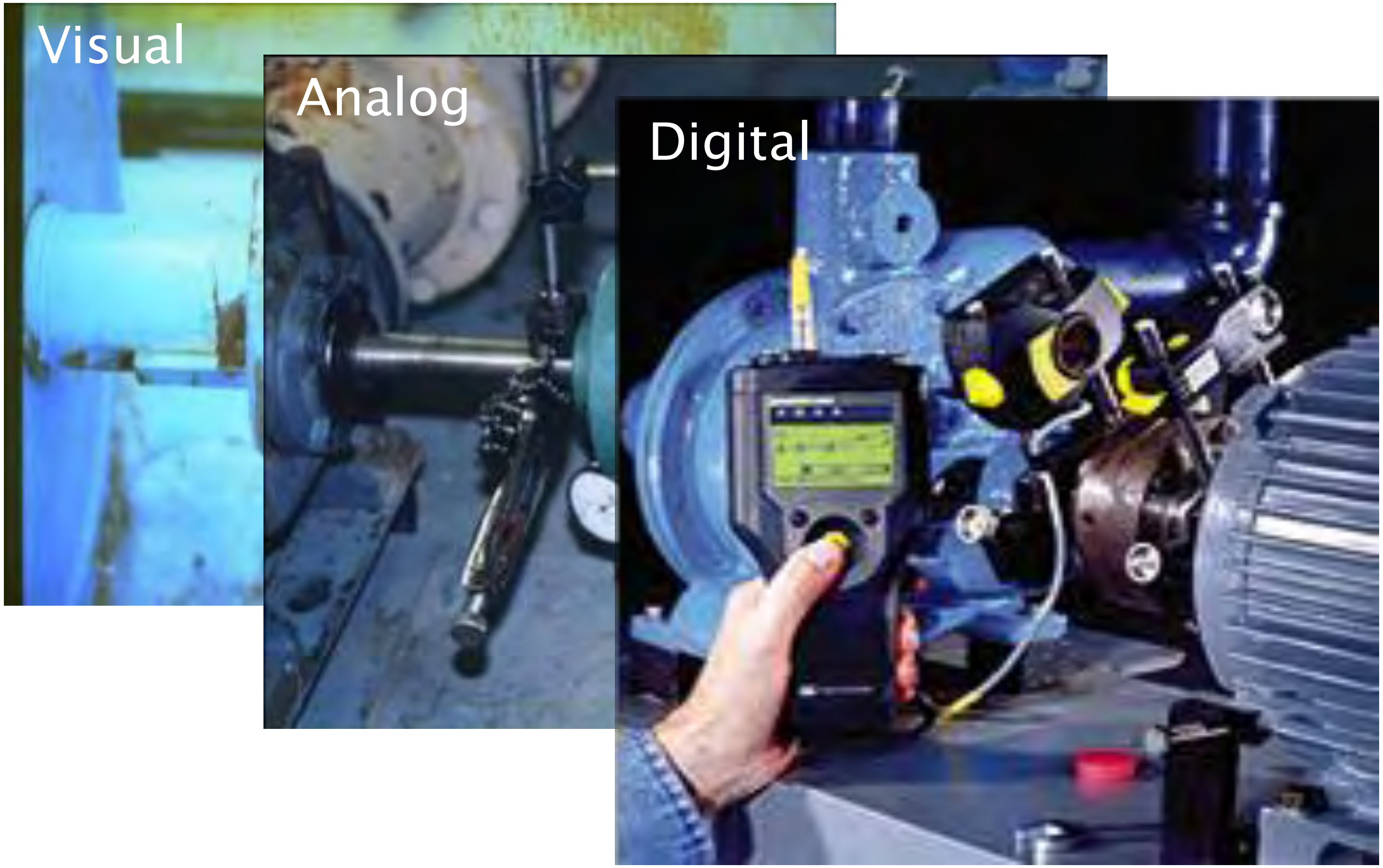
Methods to assess collection system conditions

- Smoke testing
- Dye testing
- Lamping
- Video inspection (CCTV)
- Sonar
- Ground-penetrating radar



CCTV is closed-circuit television

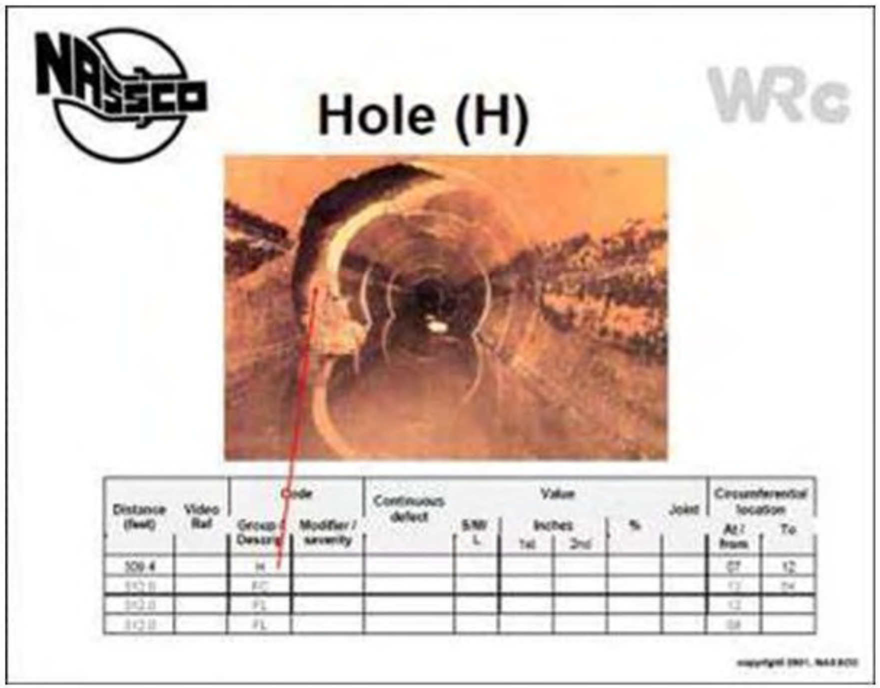
Evolution of condition technology



More condition information, faster, at lower cost from technological advances

Example: emerging national standards for pipes

Pipe Assessment Certification Program (PACP)



From National Assoc. of Sewer Service Companies (NASSCO)
& Water Research Center (WRC), *Manual of Defect Classification*

Emerging national standards for pipes

*Structural defect scores - Pipe sewers

Defect	MSCC Code	Description	Score
Longitudinally displaced joint / Open joint	OJM	Medium < 1*pipe thickness	1
	OJL	Large > * pipe thickness	2
		if soil visible grade as a hole	165
Radially displaced joint	JDM	Medium < 1* pipe thickness	1
	JDL	Large > 1* pipe thickness	2
		> 10% diameter & soil visible	80
Cracked	CC	Circumferential	10
	CL	Longitudinal*	10
		Complex*	40
		Helical*	40
	CM		
Fractured	FC	Circumferential	40
	FL	Longitudinal*	40
		Complex*	80
		Helical*	80
	FM		
Broken	B		80
Hole	H	Radial extent <¼	80
		Radial extent ¼+	165
Collapsed	X		165

*Abstract from Sewerage Rehabilitation Manual (Fourth Edition)

From National Assoc. of Sewer Service Companies (NASSCO)
& Water Research Center (WRC), *Manual of Defect Classification*

Condition assessment protocol (CAP)

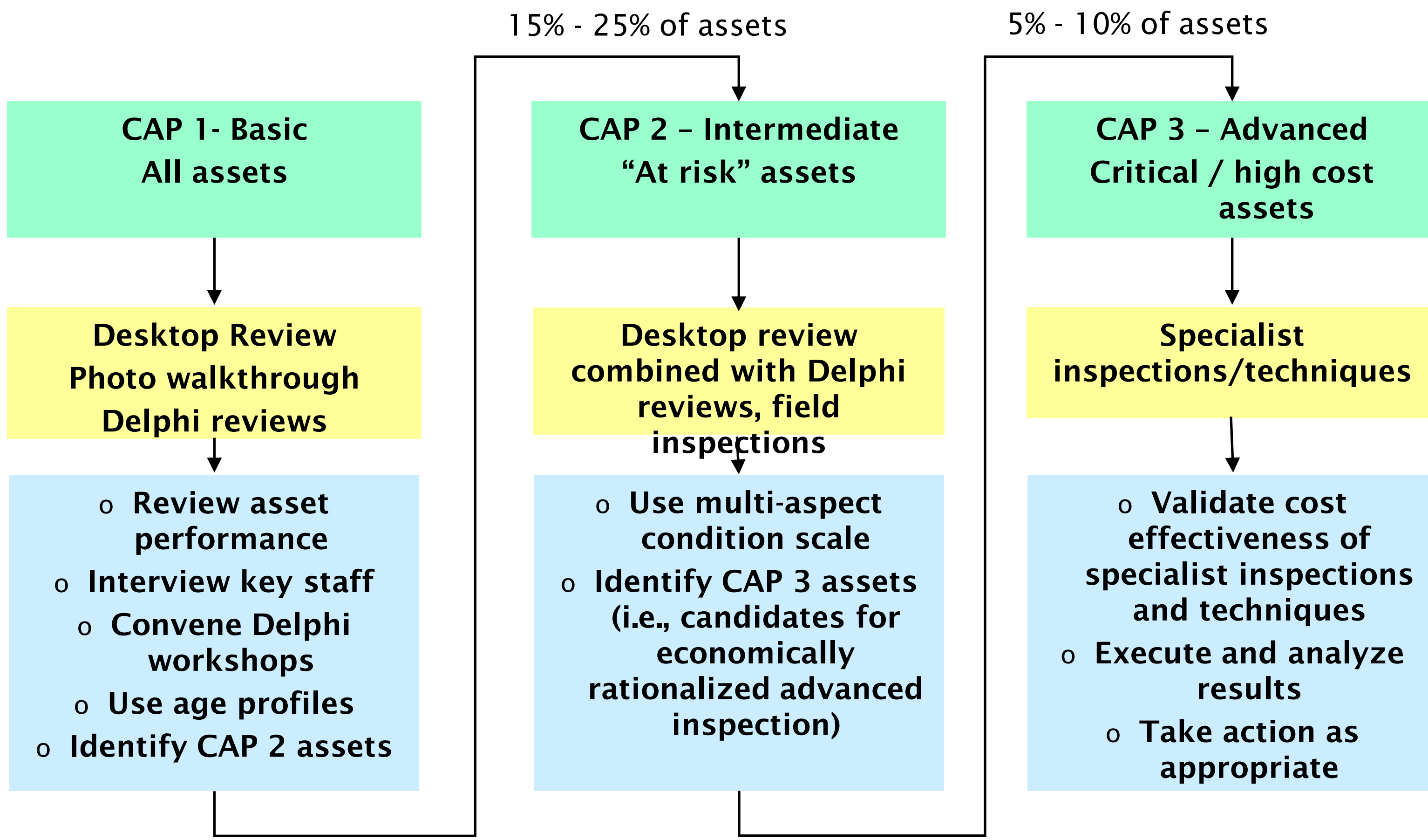
Which assets? What information? How used?

CAP 1	Simple scoring system, e.g., 1-5, or 1-10
CAP 2	Matrix scoring system with multiple distress factors and weightings to derive a score
CAP 3	Use of sophisticated techniques to determine the *residual life to intervention* or end of physical life

Characteristics of a good CAP

- Focused on *remaining useful life*, rather than just condition score
- Carefully defined, with good written protocol
- Built around *business risk assessment* (“critical assets”)
- Consistently applied (across time, across inspectors)
- Cost effective, using smart *data collection techniques*

A staged approach to condition assessment



Level 1 assessment score sheet – structural condition

Physical Condition Grade – Rating Guidelines	
1 Excellent	Asset is like new, fully operable, well maintained, and performs consistently at or above current standards. Little wear shown and no further action required.
3 Good	Asset is sound and well maintained but may be showing some signs of wear. Delivering full efficiency with little or no performance deterioration. Virtually all maintenance is planned preventive in nature. At worst, only minor repair might be needed in the near term.
5 Moderate	Asset is functionally sound, showing normal signs of wear relative to use and age. May have minor failures or diminished efficiency and some performance deterioration. Likely showing modest increased maintenance and/or operations costs. Minor to moderate refurbishment may be needed in the near term.
7 Poor	Asset functions but requires a sustained high level of maintenance to remain operational. Shows substantial wear and is likely to cause significant performance deterioration in the near term. Near term scheduled rehabilitation or replacement needed.
9 Very Poor	Very near end of physical life. Substantial on-going maintenance with short, recurrent maintenance intervals required to keep the asset operational. Unplanned corrective maintenance is common. Renewal (refurbishment or replacement) is expected in near term.
10 Failing	Effective life exceeded and/ or excessive maintenance cost incurred. A high risk of breakdown or imminent failure with serious impact on performance. No additional life expectancy; immediate replacement or rehabilitation needed.

Assessing performance: "performance" has more aspects than just "condition"!

- Condition is only a starting point for assessing asset *performance*
- Condition often only indicates the existence of structural *defects*
  - *Which defects actually drive progressive failure?*
  - *What is the rate of deterioration?*
- At *best,* condition by itself provides only *marginal* insight into:
  - Operational performance
  - Capacity
  - Reliability
  - Availability
  - Maintainability

}

Add operational level measures for these to move from condition score to *performance* score

Moving from condition to performance - attributes of performance measurement

4.
Assess condition, performance

- **Physical/Structural Condition** – The current structural state of the asset resulting from an interaction of usage, age, maintenance, design and manufacturing quality, initial construction management, and operating environment.
- **Operational/Process Condition** – The current ability of the asset to meet operational requirements now and in the foreseeable future. Process condition is substantially influenced by required levels of service/asset performance, technical obsolescence, operations and maintenance policies and history, and design effectiveness/process efficiency.
- **Reliability** – the ability of an asset to perform its required function(s) under stated conditions for a specified period of time; reliability is often considered as "how frequently an asset fails".
- **Availability** – the percentage of time that an asset is capable of functioning relative to the time that the user expects it to function (conversely, unavailability is the percentage of time that an asset is not able to do its job); availability is largely a function of the frequency of breakdowns *and their duration*.
- **Maintainability** – those characteristics of design and installation which determine the probability that a failed asset can be restored to its normal operable state within a given timeframe using prescribed practices and procedures. Its two main components are serviceability (ease of conducting scheduled inspections and servicing) and reparability (ease of restoring service after a failure). This is often measured in terms of "Mean time to repair" or "MTTR".

Level 2 performance assessment (composite basis) worksheet

Asset Identification		Baseline Info			2010	Failure Modes		Performance Elements						Notes
Asset ID	Asset Name	Build / Install date	Refurb/ Replace Date	Design Life (Yrs)	Remaining Design Life (Yrs)	Imminent Primary Failure Mode	"At Risk" Components	Physical Condition	Operational/ Process Performance	Reliability	Availablity	Maintainability	Composite Asset Performance Score	

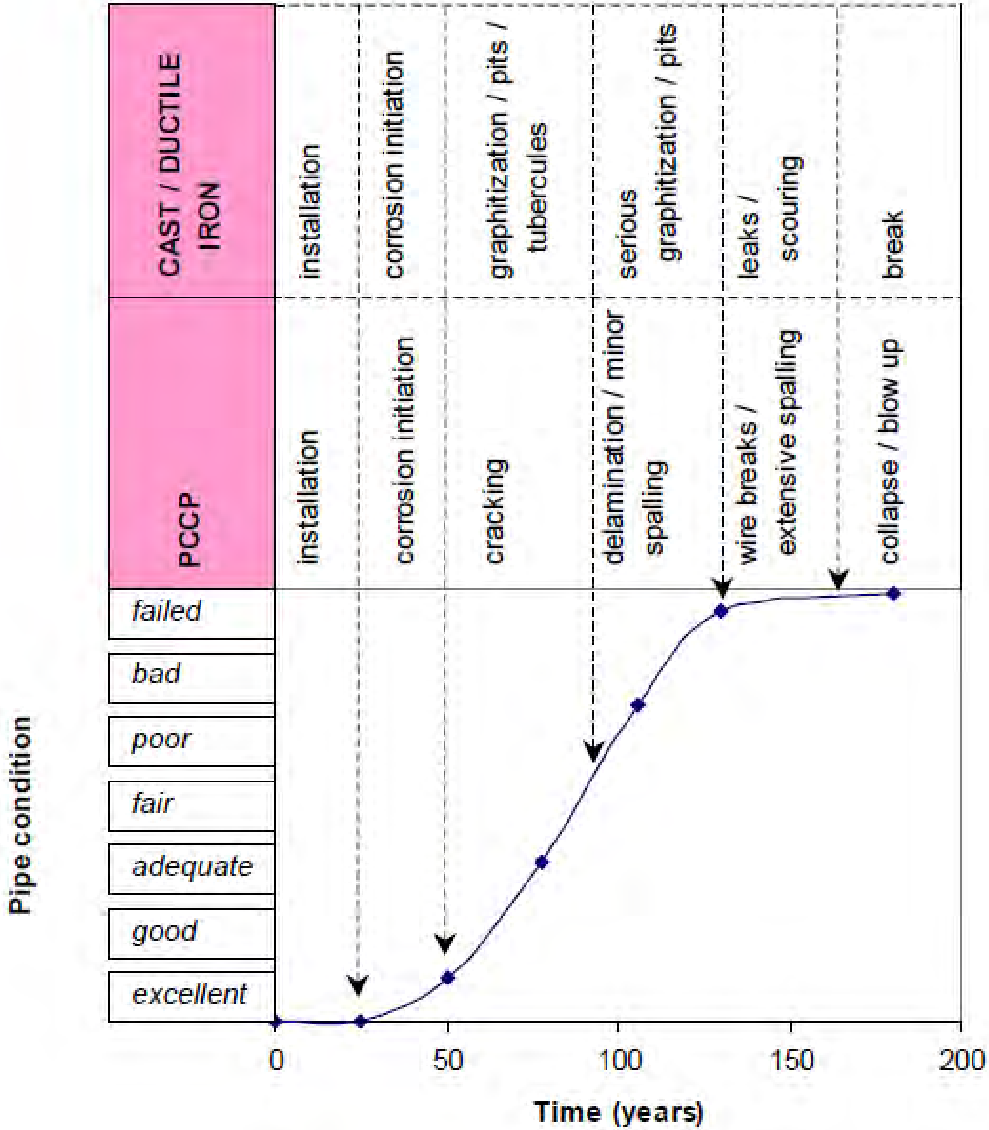
Performance Elements					
Physical Condition	Operational/ Process Performance	Reliability	Availablity	Maintainability	Composite Asset Performance Score

A composite performance scoring structure

Element	Description					
SCORE	**1**	**3**	**5**	**7**	**9**	**10**
Physical Condition	Substantially exceeds current requirements	Exceeds current requirements	Meets current requirements but with room for improvement	Obvious concerns: cost/benefit questions	Inefficient; becoming ineffective, obsolete	Failing, not capable of sustaining required performance
Operational performance	Negligible attention required	Exceeds current requirements	Meets current requirements but with room for improvement	Obvious concerns: cost/benefit questions	Difficult to sustain performance	Failing, not capable of sustaining required performance
Reliability	As specified by manufacturer	Infrequent breakdown	Occasional breakdown	Periodic breakdown	Continuous recurrent breakdown	Virtually inoperable
Availability	Virtually always operational	Out of service only for very short periods	Out of service for moderate period; moderately difficult to return to service	Increasingly difficult to return to service; parts becoming a challenge	Extensive downtime duration; difficult to return to service; parts, difficult to acquire, rare skills required	Virtually impossible to return to service; parts no longer available; unavailable trained personnel
Maintainability	Preventive maintenance only; baseline monitoring	Largely PM, some minor repair	Increasing minor corrective maintenance required; shortening of monitoring intervals	Predictive and corrective maintenance becoming dominant; frequency of work orders increasing substantially	Work orders well above average for type of asset; recurrent minor repair; close monitoring required	Corrective maintenance is frequent with recurrent patterns of failure; asset must be virtually constantly monitored or "run to failure" response readied for implementation

What is a “failure mode”?

- A failure mode is a systematic series of sequential and interrelated causal steps that (can) lead to the failure of an asset.
- We recognize two distinct levels of failure modes:
  - Primary (strategic) level failure modes
  - Tactical/operational level failure modes



7. Review likelihood of failure score

The transitional nature of failure modes

Rajani, et al., NRCC-48317
Translation of pipe inspection results into condition ratings using the fuzzy synthetic evaluation technique, 2006, p18

How failure modes relate to condition assessment

- At any given point in its life cycle, most assets have many operative failure modes and mechanics at work.
- While assessing condition to determine the state of the asset is very important to managing the asset, *irrelevant assessment is wasteful.*
- By understanding failure modes and identifying those that are most likely to drive a given asset to fail in its operating environment, we can
  - Focus our assessment on those attributes of the asset that provide the most telling "failure signatures" (what to monitor).
  - Select and apply those (rapidly improving) technologies that most directly measure the dominant failure modes (which technology(ies) to use to monitor).
  - Time the assessment most cost effectively (when to monitor)

Level 3 performance assessment scoring sheet

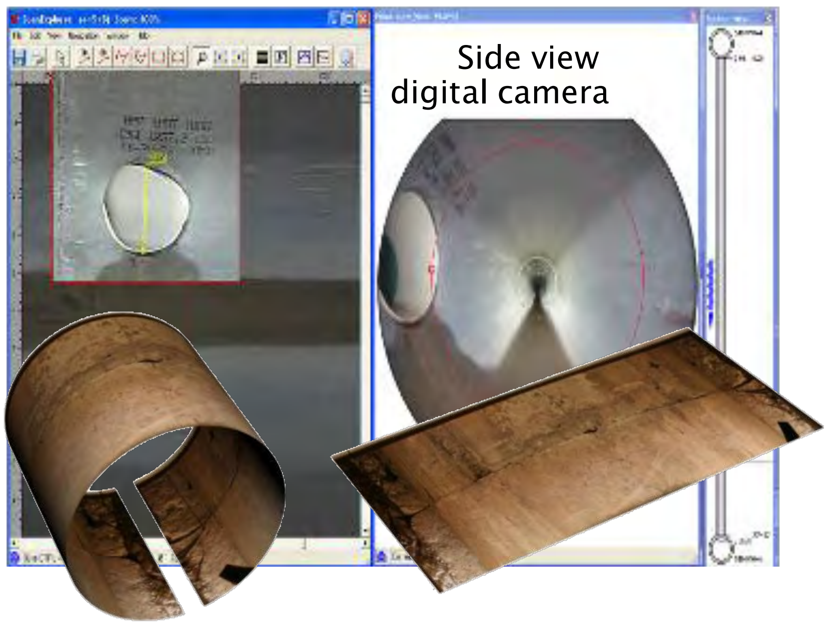
Conventional Pumps

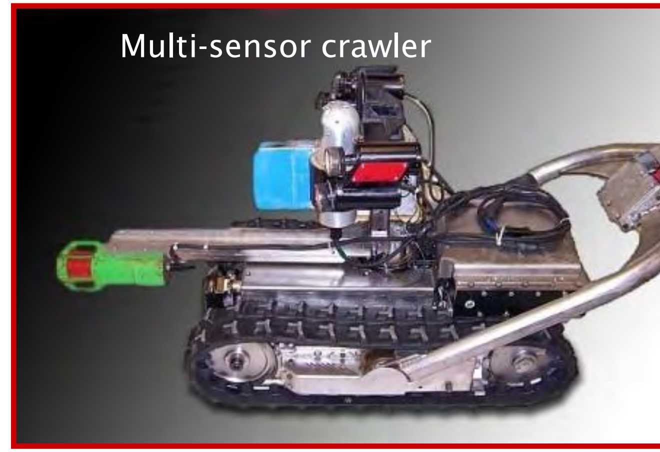
Included: Dry well & line shaft pumps | Centrifugal pumps | Vertical multi-stage booster pumps | Screw pumps

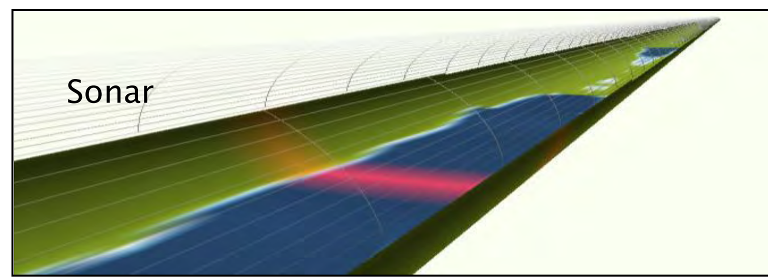
	Aspect	Distress Mode	Rating 1	Rating 2	Rating 3	Rating 4	Rating 5
CONDITION ASSESSMENT							
A	**Structure Appearance**	Leakage	Appears as new.	Minimal moisture on seals/joints.	Water dripping from seals/joints.	Water pooling on floor	Water squirting/ running onto floor.
B		Shaft, Supports, Bearing Deterioration	Shaft & supports sound - no shaft distortion or deterioration evident.	Minor shaft/ support deterioration evident, no impact on the structural strength or function.	Shaft distortion or bearing/housing wear evident, little impact on structural integrity or function.	Shaft distortion or bearing/housing wear evident and has impacted on asset integrity or function.	Significant shaft distortion or bearing/housing wear evident, high probability of fracture or failure.
C	**Use**	Motor Hours Run*	< 10,000	> 10,000	> 50,000	> 100,000	> 200,000
D	**Symptoms**	Vibration / oscillation	No unusual vibration / oscillation detectable	Minor vibration / oscillation detected	Moderate vibration / oscillation	Considerable vibration / oscillation (wristwatch shakes)	Major vibration / oscillation
E		Temperature	No unusual temperature detected	Minimal heat from casing using hand	Heat detected by hand	Heat detected by hand is uncomfortable	Heat too high to assess by hand
F		Noise	No unusual noises detected.	Slight whine/rattle detected.	Moderate whine/rattle detected, easily heard over pump noise.	Loud whine/rattle.	Disturbingly loud operation/vibrations.

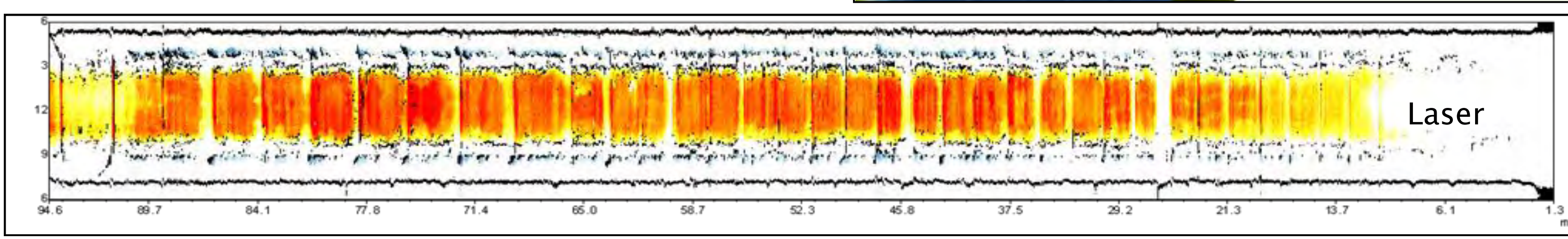
Notes: *Motor hours run and corresponding condition rating will depend on the type of pump and the application the pump is used for (i.e. thickened sludge conveyance versus influent wastewater).

Emerging sewer inspection tools and technologies









Feeney et al, White Paper on Condition Assessment of Wastewater Collection Systems; EPA/600/R-09/049 | May 2009 | www.epa.gov /nrmrl

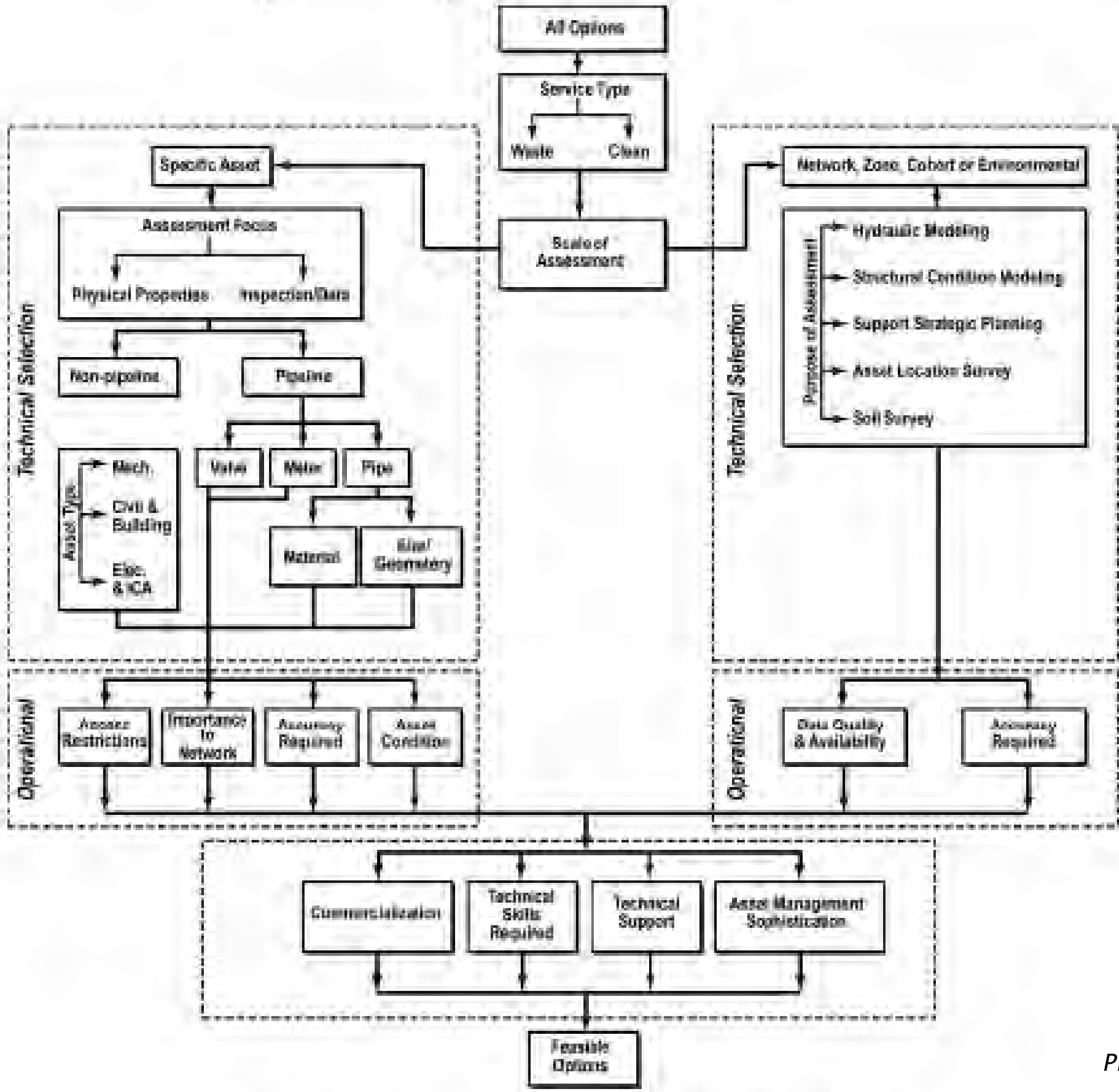


Figure 6-2 Conceptual overview of pathways in the tool selection Expert System.

Selecting a suitable condition assessment technique

Condition assessment technology is now remarkably robust

Protocols For Assessing Condition And Performance Of Water And Wastewater Assets; WERF Condition Assessment Protocols (CAP) Project (Project 03-CTS-20CO) (484 pages) December 2006

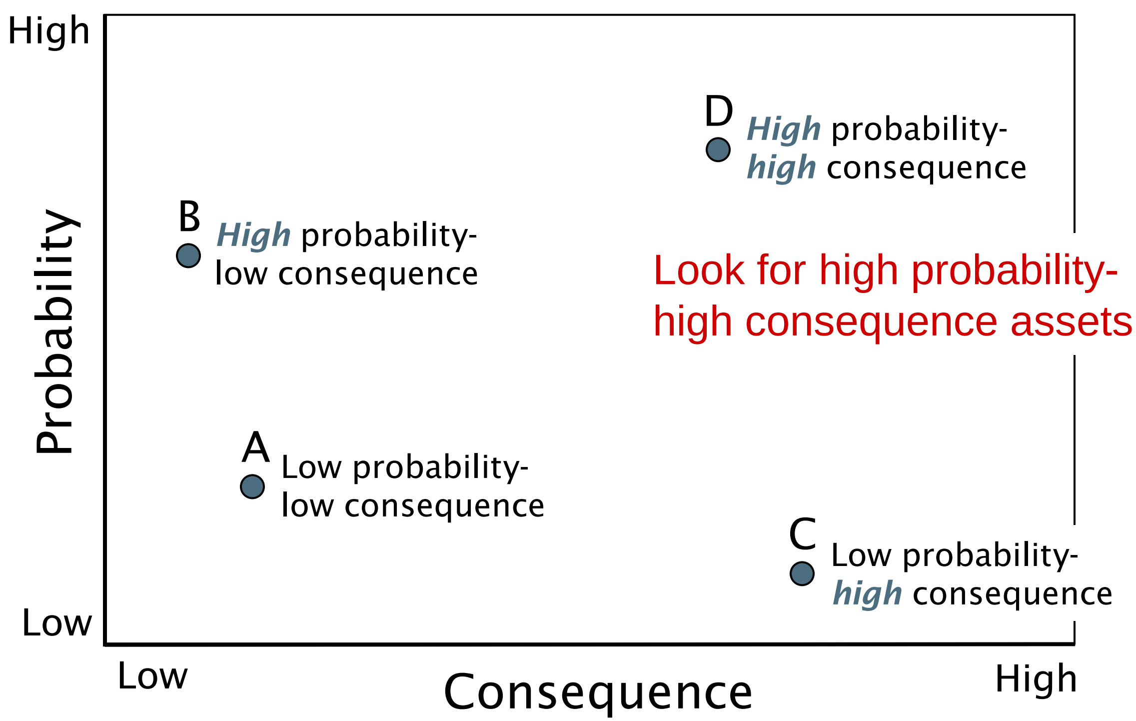
Seven smart ideas for condition data collection

1. *Business risk-driven,* with focus first on high risk, high consequence assets
2. *Problem assets-profiled*, noting that 20% of assets cause 80% of problems
3. *Sampling approach*
4. *Stepped approach*, applying more sophisticated assessment techniques to higher-cost, higher business risk-assets
5. *Failure mode-guided*, do I need condition data?
6. *Root cause-driven,* (Bayesian probability, SCRAPS)
7. *Valued judgment/Delphi approach*, as supplement to minimal data

BRE is business risk exposure; SCRAPS is Sewer Cataloging, Retrieval, and Prioritization System

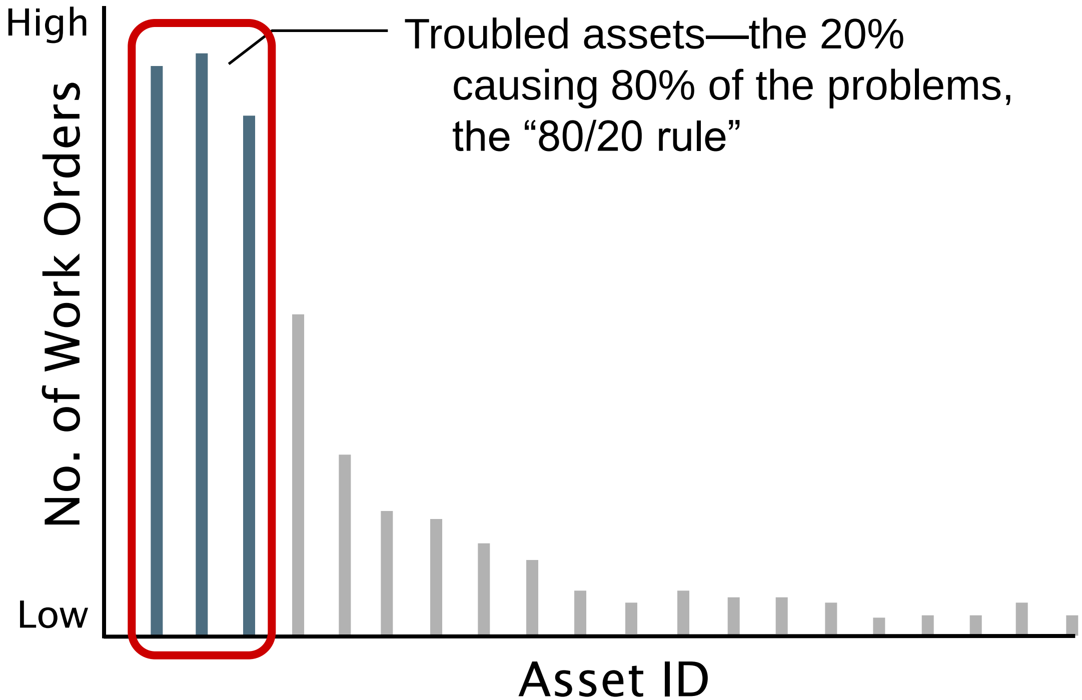
Idea 1, business risk-driven

What is probability of failure? What is consequence of failure?



Idea 2, problem assets-profiled

Do we know which are our problem assets?



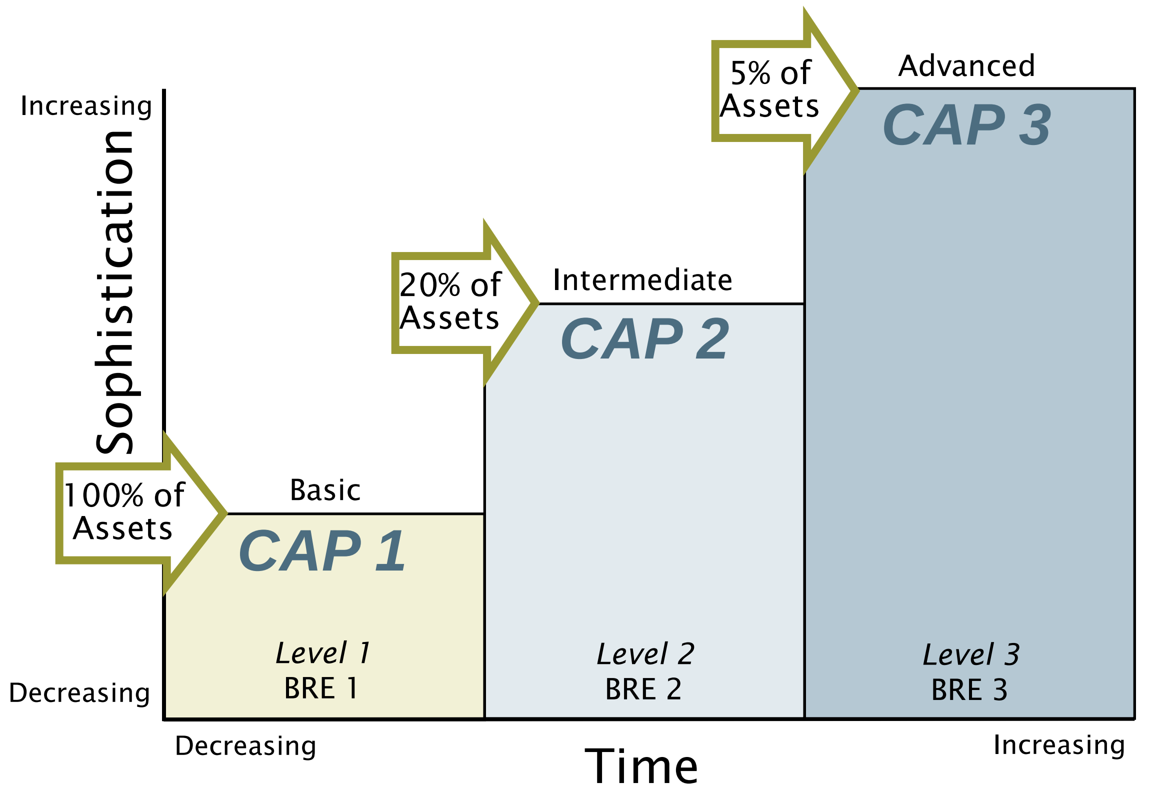
Idea 3, sampling approach

Statistically-sound, validated sampling can render high level of decision confidence at relatively low cost…

- Using *larger* sample size for *more critical* assets and *smaller* size for *less critical*
- Building sample collection around *root causes* of failure—understanding your *failure modes*

Idea 4, stepped approach

Levels of sophistication in condition assessment



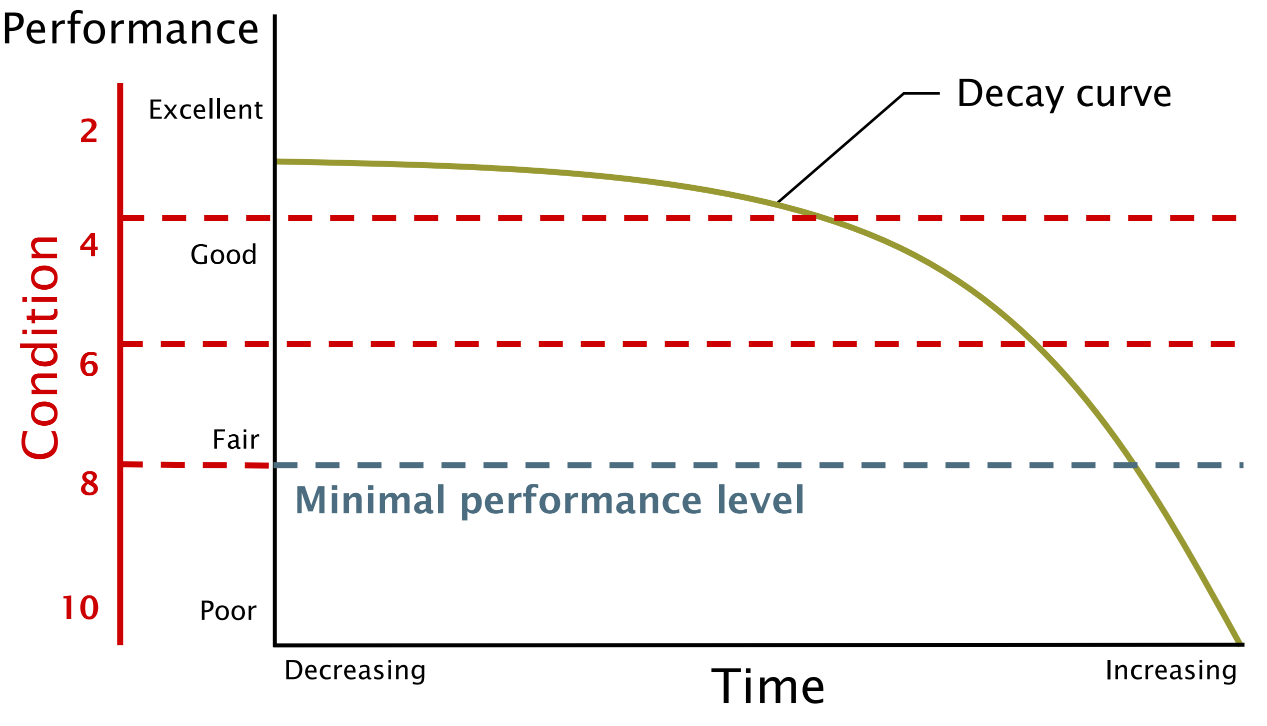
BRE is business risk exposure, CoF is consequence of failure, PoF is probability of failure, MTBF is mean time between failures

Idea 5, failure mode-guided

Failure Mode	*Definition*	*Tactical Aspects*	*Management Strategy*
Capacity	Volume of demand exceeds design capacity	Growth, system expansion	(Re)design
LOS	Functional requirements exceed design capability	Codes & permits: NPDES, CSOs, OSHA, noise, odor, life safety; service, etc.	(Re)design
Mortality	Consumption of asset reduces performance below acceptable level	Physical deterioration due to age, usage (including operator error), acts of nature	O&M optimization, renewal
Efficiency	Operations costs exceed that of feasible alternatives	Pay-back period	Replace

NPDES is National Pollutant Discharge Elimination System, CSOs are combined sewer overflows, and OSHA is Occupational Safety and Health Administration

Tying condition score to asset failure



Idea 6, root cause-driven (Bayesian)

- *"Valued judgment"* is used to develop *failure variables and propositions* (sequence of causes of failure)
- *"Valued judgment"* is used to assign *conditional probabilities* (likelihood of occurrence)
- *"Causal path"* networks are developed relating *"root cause"* to functional failure
- *Probabilities* are assigned to each of the path elements

What is SCRAPS?

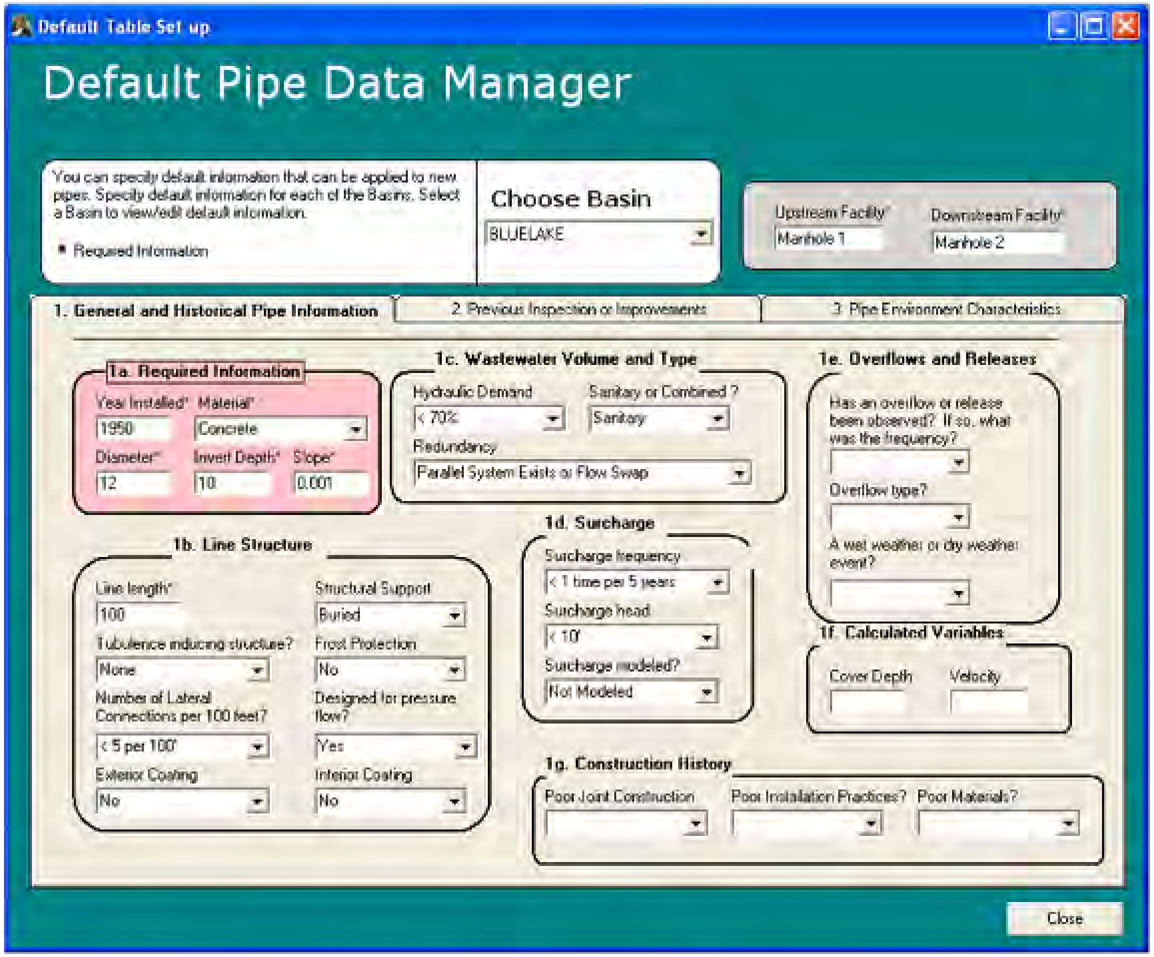
Sewer Cataloging, Retrieval, and Prioritization System (SCRAPS)

Courtesy of WERF and Brown & Caldwell

Example of Bayesian probability

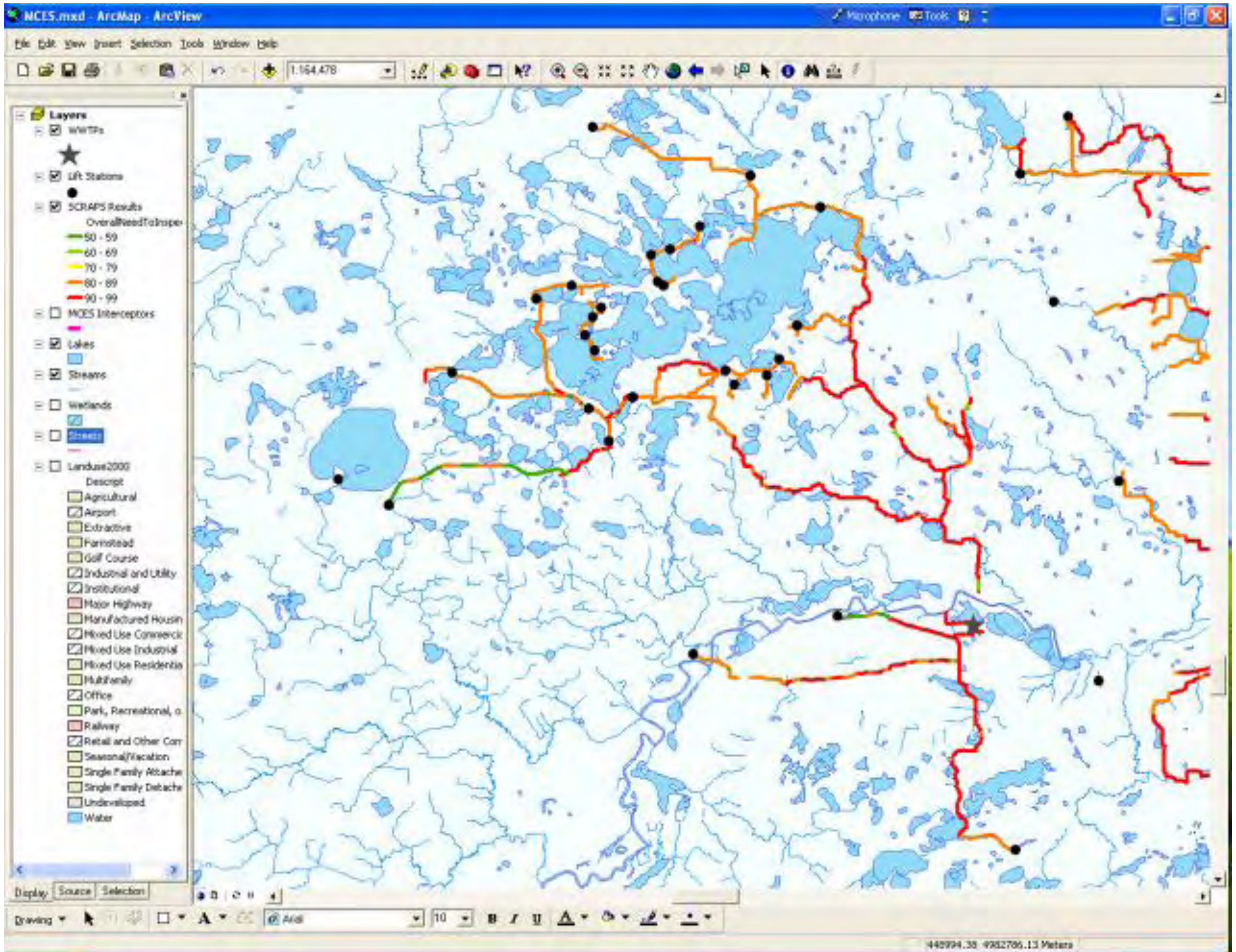
- *Proposition:* Sewer joint failures are common when the sewer is in marshy soil without support
- Or, equivalently, in Bayesian terms
  - If probability of marshy soil is *high*
  - And probability of sufficient support is *low*
  - Then *probability of joint failure is high*

Default data manager



Courtesy of WERF and Brown & Caldwell

View of pipe information from SCRAPS



Courtesy of WERF and Brown & Caldwell

Idea 7, valued judgment/Delphi approach supplements minimal data

"Valued judgment" is used to assign condition scores

- Assemble team of most-knowledgeable personnel
- Poll each member for opinion on condition score and why
- Augment with work order data and failure patterns
- Use photos and process schematics
- Facilitate group consensus through discussion

Important note on condition assessment

- Condition assessment is not an end in itself, but is a *means* to an end
- The *end* is to determine *remaining useful life*
- *Good-Fair-Poor*-type ratings have little utility *unless* they lead to an effective estimate of remaining useful life

The remaining useful life of an asset is *what we have left to try to manage*

Key points from this session

What condition is it in?

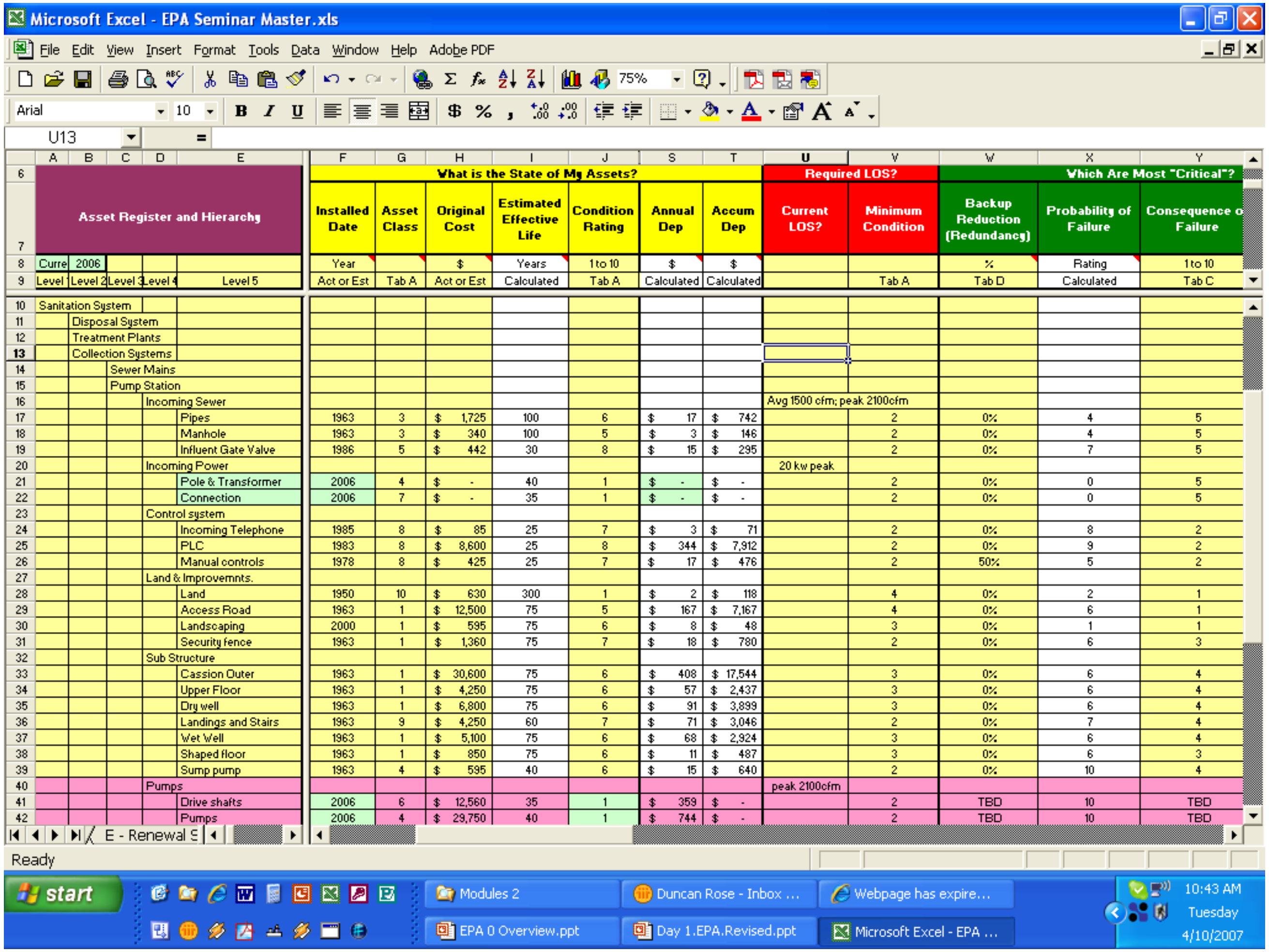
Key Points:

- Condition assessment rating scales must project remaining useful life to be useful for decision-making
- To be most cost-effective, condition assessment must be guided by the same core concepts that guides all AAM – “failure modes” and the likelihood and consequences of failure

Associated Techniques:

- Condition assessment technology
- Condition rating protocol

Tom's spreadsheet



Row	Asset Register and Hierarchy	Installed Date	Asset Class	Original Cost	Estimated Effective Life	Condition Rating	Annual Dep	Accum Dep	Current LOS?	Minimum Condition	Backup Reduction (Redundancy)	Probability of Failure	Consequence of Failure
6		What is the State of My Assets?							Required LOS?		Which Are Most "Critical"?		
8	Curre 2006	Year		$	Years	1 to 10	$	$			%	Rating	1 to 10
9	Level 1 / Level 2 / Level 3 / Level 4 / Level 5	Act or Est	Tab A	Act or Est	Calculated	Tab A	Calculated	Calculated		Tab A	Tab D	Calculated	Tab C
10	Sanitation System												
11	Disposal System												
12	Treatment Plants												
13	Collection Systems												
14	Sewer Mains												
15	Pump Station												
16	Incoming Sewer								Avg 1500 cfm; peak 2100cfm				
17	Pipes	1963	3	$ 1,725	100	6	$ 17	$ 742		2	0%	4	5
18	Manhole	1963	3	$ 340	100	5	$ 3	$ 146		2	0%	4	5
19	Influent Gate Valve	1986	5	$ 442	30	8	$ 15	$ 295		2	0%	7	5
20	Incoming Power								20 kw peak				
21	Pole & Transformer	2006	4	$ -	40	1	$ -	$ -		2	0%	0	5
22	Connection	2006	7	$ -	35	1	$ -	$ -		2	0%	0	5
23	Control system												
24	Incoming Telephone	1985	8	$ 85	25	7	$ 3	$ 71		2	0%	8	2
25	PLC	1983	8	$ 8,600	25	8	$ 344	$ 7,912		2	0%	9	2
26	Manual controls	1978	8	$ 425	25	7	$ 17	$ 476		2	50%	5	2
27	Land & Improvemnts.												
28	Land	1950	10	$ 630	300	1	$ 2	$ 118		4	0%	2	1
29	Access Road	1963	1	$ 12,500	75	5	$ 167	$ 7,167		4	0%	6	1
30	Landscaping	2000	1	$ 595	75	6	$ 8	$ 48		3	0%	1	1
31	Security fence	1963	1	$ 1,360	75	7	$ 18	$ 780		2	0%	6	3
32	Sub Structure												
33	Cassion Outer	1963	1	$ 30,600	75	6	$ 408	$ 17,544		3	0%	6	4
34	Upper Floor	1963	1	$ 4,250	75	6	$ 57	$ 2,437		3	0%	6	4
35	Dry well	1963	1	$ 6,800	75	6	$ 91	$ 3,899		3	0%	6	4
36	Landings and Stairs	1963	9	$ 4,250	60	7	$ 71	$ 3,046		2	0%	7	4
37	Wet Well	1963	1	$ 5,100	75	6	$ 68	$ 2,924		3	0%	6	4
38	Shaped floor	1963	1	$ 850	75	6	$ 11	$ 487		3	0%	6	3
39	Sump pump	1963	4	$ 595	40	6	$ 15	$ 640		2	0%	10	4
40	Pumps								peak 2100cfm				
41	Drive shafts	2006	6	$ 12,560	35	1	$ 359	$ -		2	TBD	10	TBD
42	Pumps	2006	4	$ 29,750	40	1	$ 744	$ -		2	TBD	10	TBD