Hydrometeorology Testbed (HMT) Program

Developing New Tools to Help Meet the Nation's Water Resource Challenges in a Changing Climate

HMT

Implementation Plan for Science & Service

2009

NOAA's Hydrometeorology Testbed (HMT) Program

Developing New Tools to Help Meet the Nation's
Water Resource Challenges in a Changing Climate

Accelerating Hydrometeorological Research and Development and
The Infusion of Research & Technology Into Forecasting Operations

Implementation Plan for HMT Science & Services

Updated: November 18, 2009

This document comprises the HMT Science Plan: it describes the who, what, why, and where of HMT, and how this national program conducts research and development to improve services through regional implementation. It is a living document, to be updated annually.

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Executive Summary

The Hydrometeorology Testbed (HMT) is a research program aimed at accelerating the research, development, and infusion of new technologies, models, and scientific results from the research community into daily forecasting operations of the National Weather Service (NWS) Weather Forecast Offices (WFOs), River Forecast Centers (RFCs), and the National Centers for Environmental Prediction (NCEP). HMT has been identified in the NWS Hydrology Science and Technology Implementation Plan (STIP) as a key new R&D approach for improving flood forecasts, and its implementation has been directed to NOAA's Weather and Water mission goal. The diversity of talent and expertise across NOAA and other federal, state, and local agencies is being harnessed in HMT by building partnerships that breakdown traditional 'stovepipes'. The cross-discipline structure of HMT includes researchers and forecasters forming new working relationships that are time efficient and effective in realizing improved water services.

> *HMT has demonstrated that advanced observational, data assimilation and modeling systems can be deployed for productive use by NWS RFC and WFO operational offices and NCEP operational staff, and their federal, state, and local agency partners. Additional coordination will be directed to placing HMT advanced tools into operational settings of the partners.*

HMT is a national testbed strategy that is implemented regionally. In practice, this means that resources are focused for a number of years in one region of the country to address the hydrometeorology problems in that region. Then, the regional project is shifted to another region of the country while maintaining a continued, "legacy" effort in the original focus region. Each project will run for several years (nominally for five or more years) in each regional demonstration setting to determine the most useful new tools for improving precipitation and runoff forecasting methods. The proven successful tools will remain in place and will be duplicated as the HMT moves to the next region.

> *HMT has demonstrated that the regional testbed strategy is an effective way to concentrate the efforts of researchers and operational agencies on the particular hazardous weather phenomenon of that region. Further, the process of HMT planning and deployment provides insights into how multiparticipant projects can be designed and implemented for achievement of improved water services.*

The first phase of HMT is an outgrowth of NOAA's CALJET and PACJET projects from 1997–2003 on the West Coast. HMT-West targets California's flood-vulnerable American River Basin as the first full-scale deployment of this highly instrumented facility, deployed during the period from 2005 through 2011. Preliminary, small-scale tests of HMT facilities were conducted in California's Coast Range in 2004 (HMT-04), and the HMT was extended to the western slopes of the Sierra Nevada for the winter of 2004-2005. The 2008–2009 winter season is the fourth and most comprehensive deployment in the American River Basin and associated region to date. HMT-West is expected to peak in 2009–2011, before transitioning to a legacy mode of operations.

Following the California demonstration, HMT facilities will be sequentially deployed to other regions of the nation to address serious hydrometeorology problems that are unique to those locations. The next regional testbed is targeted to begin in 2011 (or thereafter, pending support) in the southeastern United States: planning is underway for HMT-Southeast and is focused on the Tar-Neuse River Basins of North Carolina.

> *Staged deployment of the HMT observational and forecasting systems has allowed researchers to learn about and focus on the primary drivers of extreme precipitation and associated flooding and flash flooding, and to validate advanced data assimilation and forecast tools through users charged with forecast and warning operations. It is anticipated that successful aspects of the HMT will remain deployed in the region as a legacy to provide continuing support for operations.*

Unlike typical research field projects, HMT operates as a demonstration with forecasters and researchers joining forces in the operational setting. HMT yields research findings and field-tested methods that can be implemented into NOAA's operational forecast and information services. These include improved algorithms, better models, new observations or better use of existing observations, new diagnostic techniques, and forecaster training modules describing new tools or insights into physical processes. A key output of HMT is an accurate estimate of the spatio-temporal distribution of current and forecast precipitation over selected pilot study watersheds. These observations are then used to evaluate existing and new forecast models and other forecast tools, such as those needed for the NWS watch-warning system and streamflow forecasting system.

The major activity areas of HMT include:

- Quantitative Precipitation Estimation (QPE)
- Quantitative Precipitation Forecast (QPF)
- Snow Level and Surface Snow Information
- Hydrologic Applications
- Debris Flow
- Verification
- Decision Support Tools

Quantitative precipitation estimation is difficult for a variety of reasons, including shallow rain processes, practical difficulties in deploying and maintaining rain gauge networks, limitations of radar in detecting precipitation in zones with beam blockages, over-shooting or coarse radar resolution, algorithmic uncertainties, and challenges in determining the precipitation phase near or at the surface. HMT-West precipitation gauges, weather radars, and multisensor data assimilation methods enable scientists to form a more complete picture of winter precipitation events over the Sierras, test new methods for deriving precipitation from more commonly available remote observing platforms, and determine the impact of these QPEs in hydrologic models.

> *HMT has demonstrated that coordinated deployment of a wide spectrum of sensors, data assimilation techniques, and models can provide a more complete picture of winter precipitation events and hydrologic responses over complex terrain. However, gaps remain in the sensor coverage and analysis capabilities that require further development and testing to achieve a fully complete representation of QPE.*

Quantitative precipitation forecasts are a key element for improving lead-time for extreme precipitation events and consequent hydrological forecasts. Various activities have been implemented in HMT-West to provide improved QPFs, including numerical weather prediction modeling (NWP), an AR water vapor flux tool, reforecasting for statistical postprocessing, and subseasonal forecasting based on patterns of the Madden-Julian Oscillation (MJO) and other large-scale phenomena. The principle ensemble systems being used in the HMT are configurations of the Weather Research and Forecasting (WRF) Model, the NCEP Short-range Ensemble Forecast System (SREF) and the North American Ensemble Forecast System (NAEFS), with efforts directed to designing, implementing, maintaining, and evaluating the ensemble modeling systems, and new statistical postprocessing techniques, especially for probabilistic quantitative precipitation forecasts.

> *HMT has fostered development of a number of new approaches for QPF which address lead time scales ranging from 0–3 days, 3–5 days, 5–14 days and greater than 14 days. Parallel testing of these approaches provides new insights into the efficacy of singular and combined versions for improving forecast lead times. Gaps are evident, however, in the data assimilation procedures, the appropriateness of the various products for operational use by the RFCs, WFOs and NCEP, coordination of the various products, assignment of computing resources, and verification of forecast products; these gaps are the focus of continuing research.*

Snow level and surface snow information are important because the snow level (SL) determines the amount of area in a basin that will receive rain versus snow during a particular storm, key factors governing the amount of water that is available for runoff and the potential for flooding. HMT has developed, implemented, and evaluated a technique that uses profiling radars to automatically detect the altitude of the SL during precipitation. HMT is now using these systems to validate gridded observational estimates and forecasts of SL through intensive field monitoring of storm events. This validation work will eventually lead to better integration of radar SL estimates into operational forecasting.

> *HMT has yielded new sensors and techniques for SL nowcasting, QPE and forecast verification. A patented SL algorithm has been implemented and provides products used by the RFC for operational hydrologic forecasting. Further, as part of the HMT-West legacy, NOAA has embarked on projects with the California Department of Water Resources (DWR) and the California Energy Commission (the CalWater project) to provide radar and wind profiler instrumentation to support continuing research on snow weather processes in the Sierras.*

Hydrologic applications build on the hydrometeorological observations and forecasts to obtain improved river simulations and forecasts. Activities include: 1) evaluation of advanced observations of rain and snow, temperature, soil moisture, and other variables in the context of operational forecasting at the CNRFC and companion WFOs (Sacramento, Monterrey and Reno); 2) hydrologic research in the North Fork American River as part of the second phase of the distributed model inter-comparison project (DMIP-2); and 3) soil moisture monitoring in support of distributed model implementation.

> *HMT datasets are being used to support WFO and RFC hydrologic forecasting operations. The high-resolution HMT datasets also provide the basis for pilot testing of new hydrologic modeling approaches of the AHPS and ESP by the CNRFC, and the DMIP-2 by OHD. Planned deployment of additional gap-filling radars is intended to provide a better definition of orographic rainfall in the mountainous terrain. Soil moisture networks are being deployed throughout California (through HMT and EFREP), in Arizona, and in Colorado.*

Debris flows are gravity-driven mixtures of sediment and water that are most commonly initiated when heavy rainfall or rapid snowmelt mobilizes soil on steep slopes. Areas burned by brush fires in California are shown to be particularly susceptible to debris flows. Accurately measuring rainfall over potential debris flow basins is one of the more difficult challenges associated with applying intensity-duration thresholds. Radar-observed quantitative precipitation estimates (QPE) provide one way to estimate the areal coverage of precipitation, if the radar is properly sited and calibrated.

> *HMT will contribute to the multiagency collaboration that is providing enhanced QPE and QPF products to support debris flow watch and warning product development by the responsible WFOs and RFCs, primarily through the FFMP application.*

Verification is an essential activity that provides quantifiable information on improvements in forecast skill. The HMT QPF verification project has several goals, including 1) the identification, assessment, and assurance of verification data quality, including QPE; 2) the establishment of effective techniques for the verification of probabilistic forecasts; and 3) the determination of confidence levels for verification scores. Methods are applied for QPE, QPF, snow level and hydrological forecasts. Verification is also the basis for the formulation of new and/or improved performance measures.

> *One notable HMT-West outcome is the development of a new QPF performance measure based on the QPF versus QPE bias ratio for extreme precipitation events associated with land-falling Pacific winter storms. Research analyses of precipitation forecasts and estimates for events during HMT-West have also led to the development of improved verification techniques for*

ensemble QPFs. Similar advancements have been demonstrated for snow level forecasts. Planned verification activities include those for QPE, QPF and hydrologic forecasts. HMT is developing and evaluating new performance measures for QPF and snow level monitoring and prediction.

Decision support tools denote a category of activities involving placement of HMT- coordinated functionalities for use by forecasters in actual forecasting and hazardous event warning operations. This category of HMT activities includes: 1) forecaster workstation upgrades using the Advanced Linux Prototype System (ALPS), 2) flash flood monitoring and prediction (FFMP), 3) gridded forecast preparation (graphical forecast editor (GFE)), and 4) Integrated Water Resources Science and Services (IWRSS).

HMT has supported the development and operational deployment of the ALPS workstation. Two ALPS are deployed in the Sacramento Flood Operations Center (FOC), which coordinates flood response actions by the California DWR, the US Army Corps of Engineers, the US Bureau of Reclamation; and in the Monterey and Eureka WFOs. These are examples of the penetration of HMT advanced data sets and decision tools into operations by the responsible response agencies. Efforts to utilize and/or improve FFMP and GFE are also underway. This is the kind of coordination envisioned by NOAA's IWRSS concept.

Two crosscutting themes have emerged:

- Atmospheric Rivers
- Observation Systems

Atmospheric Rivers (AR) are considered a crosscutting theme of the HMT-West in that this hydrometeorological phenomenon strongly influences all of the other activities. It is becoming increasingly clear that our ability to improve predictions of many of the largest storms and floods impacting western North America, and our ability to track their progress as they propagate down the coastal margin, will depend on advancing our understanding and observations of ARs.

HMT has provided new capabilities for detection and forecasting of ARs and the contribution of this phenomenon to heavy precipitation and flood runoff events. These capabilities are demonstrated in the various specific activities described below. Continuing research seeks to improve the lead time for AR detection and to integrate advanced detection and forecasting tools into forecast operations.

HMT observational systems are an enabling theme and are the foundation for detection and forecasting of extreme precipitation events. The HMT observational systems have evolved over the past several years to incorporate a wide variety of instrumentation and data collection capabilities. Special, highly detailed observations are being collected within the broader context of the operational observing networks of the National Weather Service (NWS) and other agencies. The HMT observational strategy consists of a network providing broad regional context within which heavily instrumented river basins are nested.

The HMT program creates a unique capability within NOAA to assess new technology by understanding what needs to be measured, how to measure it, and how to extract the most useful information from these measurements. R&D continues to develop new and low-cost sensors and data assimilation techniques, which can provide the foundation for improved water services.

1 Introduction

NOAA's Hydrometeorology Testbed (HMT) Program has been developed to respond to the increased criticality of water to our nation's wellbeing. Severe weather events such as hurricanes, intense rainstorms and subsequent flooding and/or flash flooding, droughts and concerns with the impacts of climate change have led to a number of initiatives directed to improving our capacity for forecasting and warning of these phenomena. To accomplish these goals, a priority is being placed on the design and development of integrated multifunctional mesoscale observing networks and operational forecasting systems focused on a specific region. The HMT Program is comprised of regional projects called "testbeds" (e.g. HMT-West in northern California) and satellite projects known as mini-testbeds (such as the soil moisture and temperature network in Arizona).

Deployment of a regionally oriented testbed approach was a primary recommendation of a U.S. Weather Research Program workshop (summarized in Dabberdt et al. 2005a):

> "*As NOAA considers the future of its integrated regional, surface, and tropospheric observing systems, it faces a key question addressed by this workshop—how to optimize the development and deployment of new measurement systems so as to strengthen the mesoscale observation and prediction capabilities over the United States. Testbeds can point the way toward filling this need …*"

This recommendation describes a primary motivator for NOAA's HMT Program. HMT is about innovation – a relatively new model for doing applied research: HMT is a hydrometeorological research program aimed at accelerating the research, development, and infusion of new technologies, models, and scientific results from the research community into daily forecasting operations of the National Weather Service (NWS). It is one effort to build a bridge over the so-called "valley of death" that often exists between the research and development and operational communities (National Research Council, 2000). These principles are contained in HMT's mission and vision statements:

Mission

To conduct research and accelerate the development and infusion of new technologies, models, and scientific results from the research community into daily hydrometeorological forecasting operations of the National Weather Service (NWS)

Vision

To significantly increase the accuracy (verifiability) and reliability of NOAA's hydrometeorological products and services to meet the nation's growing demands for water resource information in a changing climate.

1.1 HMT's Drivers: NOAA's Strategic Goals and Mission Requirements

In this section, HMT is placed within the framework of NOAA's Strategic Plan and key performance measures

Key Societal Needs

Water is a vital resource that touches every life, every day. Thus it is almost a paradox that both too much water and too little water can be extraordinarily costly, and even deadly.

- "Water is the next oil." Managing a key natural resource (and a valuable commodity) requires advanced monitoring and predictive capabilities to reduce conflict between many competing demands, from fisheries, to agriculture, human consumption and many other uses

- On average, flooding causes more loss of life than other weather-related natural hazards, a significant fraction of which can be mitigated through more accurate forecasts and warnings
- Whether the problem is too little, or too much water, the societal impacts are profound

This dimension is explored further in section 1.2.

A National Priority has Emerged on Water Resources Information

Water resources problems are significant and getting bigger, and have created demand for NOAA and other agencies to coordinate and accelerate efforts to address these challenges. Excerpts from a briefing by NOAA Deputy Undersecratary Mary Glackin at the interagency meeting "Collaborating for a Sustainable Water Resources Future" (August 2009), include:

- Climate change and variability are dramatically impacting water availability and quality
- Socio-economic impacts of floods and droughts are escalating
- Population growth and economic development are stressing water supplies
- Increasing global demand for food and energy are causing unprecedented pressure on water resources and aquatic ecosystems
- Seamless integration of information and capabilities, and enhanced levels of collaboration, are required to address these challenges
- Each Federal water agency has an important role

NOAA's Mission

NOAA's mission is to

> *"To understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social, and environmental needs."*

The NOAA Mission Goal that is addressed most directly by HMT is to
> *"Serve Society's Needs for Weather and Water Information"* (Weather and Water)

Weather and Water's Performance Objectives

The Weather and Water formal performance objectives that are addressed most directly by HMT are

- Increase development, application, and transition of advanced science and technology to operations and services
- Increase lead time and accuracy for weather and water warnings and forecasts
- Improve predictability of the onset, duration, and impact of hazardous and severe weather and water events

Additional Weather and Water formal performance objectives addressed by HMT are:

- Reduce uncertainty associated with weather and water decision tools and assessments
- Increase application and accessibility of weather and water information as the foundation for creating and leveraging public (i.e., federal, state, local, tribal), private and academic partnerships
- Increase coordination of weather and water information and services with integration of local, regional, and global observation systems

- Enhance environmental literacy and improve understanding, value and use of weather and water information services

Weather and Water Research Areas within NOAA's Five-Year Research Plan FY2008–FY2012

- Improve weather forecast and warning accuracy and amount of lead time
- Improve water resources forecasting capabilities
- Improve NOAA's understanding and forecast capability in coasts, estuaries, and oceans

NOAA Mission Requirements/Program Objectives Addressed by HMT (from Program Charters)

Mission requirements related to the Integrated Water Forecasting (IWF) Program:

- NOAA's Role: Provide accurate and reliable water forecasts (*where, when, and how much), including*
    - Precipitation
    - Flash Flood
    - River flood
    - Estuarine water level and storm surge

Program objectives for IWF (from NEC decisional briefing December 2008) addressed by HMT:

- Advance and integrate observing systems for water resources
- Reduce 1-7 day river forecast errors by 50% and quantify uncertainty
- Provide seamless suite of summit-to-sea high resolution water quantity and quality forecasts
- Provide flood inundation forecast maps for 100% of high-impact river and coastal communities
- Couple modeling systems for rivers, lakes and estuaries

Mission requirements related to the Weather and Water Science, Technology & Infusion Program:

- Advance NOAA mission-oriented scientific understanding
- Advance NOAA mission oriented technology development
- Infuse new science and technology into NOAA forecast operations

Performance Measures

Table 1.1 Lists the current, applicable Government Performance Requirements Act (GPRA) measures (from NOAA's Annual Operating Plan) and demonstration GPRA measures under development. The major R&D activity areas required to improve forecast and warning services (technical guidance from the HMT Management Council, informed by the HMT Advisory Panel and Project Manager) are also listed.

HMT Links Science and Technology Advances

HMT links science and technology (S&T) advances and NWS forecast improvements by fostering mission-oriented R&D and infusion of advances into operations. This section is from the draft "Capstone" document supporting the "NWS S&T Roadmap" currently under development.

A core challenge for S&T is how to measure science and technology research performance, including both the underlying advances needed in S&T to enable future breakthroughs in NOAA's services, as well as the

Table 1.1 GPRA and Demonstration Performance Measures for Forecasts and Warnings Addressed by HMT				
Type	**Forecast or warning**	**Statistical form**	**Issuing Offices**	**Major R&D activities required**
GPRA	1 inch precipitation	Threat score	NCEP HPC	A, F, G
GPRA	River flood warning	Lead time, accuracy	RFCs, WFOs	A, B, C, D, F, G
Demo	Extreme precipitation	POD/FAR/CSI/MAE	NCEP, RFCs	A, B, E, F, G
Demo	Snow level	Altitude error	RFCs	A, D, F
HMT's Major Activity Areas for R&D and Service Improvements				
A	Quantitative precipitation forecasting (QPF)			
B	Quantitative precipitation estimation (QPE)			
C	Snow information (snow level and snow on ground)			
D	Hydrology (flooding, soil moisture, runoff and streamflow)			
E	Debris flow			
F	Verification			
G	Forecaster decision support tools			

near-term incremental improvements that typically build on existing operational tools. Key constraints should be recognized in establishing appropriate measures, i.e., S&T advances are a foundation of NOAA's service improvements, yet are often not initially measurable in the "service" GPRA scores. Improving "service" GPRA scores requires "service" programs to adopt new methods, yet this may have a cost and require services to let go of existing methods. Thus a balance must be struck: while research suggests fast improvements in GPRA scores may be possible, operational goals must be reasonably achievable or the risk of failure is increased. Standard measures of scientific and technical staff productivity include patents and formal publications that do not directly link to service improvements, and yet are critical to career advancement and are standards of productivity used broadly in the S&T community.

To strike this balance, a mix of the following approaches in measuring progress on implementation of the S&T Roadmap is recommended:

i. Internal measures suitable for state-of-the-art science & technology development; i.e., measure the innovation that underpins future breakthrough advances (the S&T "push")

ii. "Infusion-oriented" measures, including testbed demonstrations of proposed new GPRA measures

iii. Internal measures in "service" programs tracking implementation of infusion; i.e., measure the services' "pull" for science and technology

iv. Internal measures tracking the rate at which innovation is assimilated into forecast operations and the rate at which outdated forecast tools are discontinued

The overall concept is to use "demonstration" GPRA measures (i.e., "stretch" versions of current goals and entirely new goals) to measure potential service improvements and appropriate measures of science and technology progress (Figure 1.1). Key elements of this strategy are:

- Internal "stretch" GPRA score goals can be set higher in testbeds than in full operations
- Adoption of new methods for full operations requires proof of concept
- Proof of concept can be demonstrated by limiting tests to small areas, times, and tools
- By limiting the scope of tests, the costs can be kept within reasonable bounds

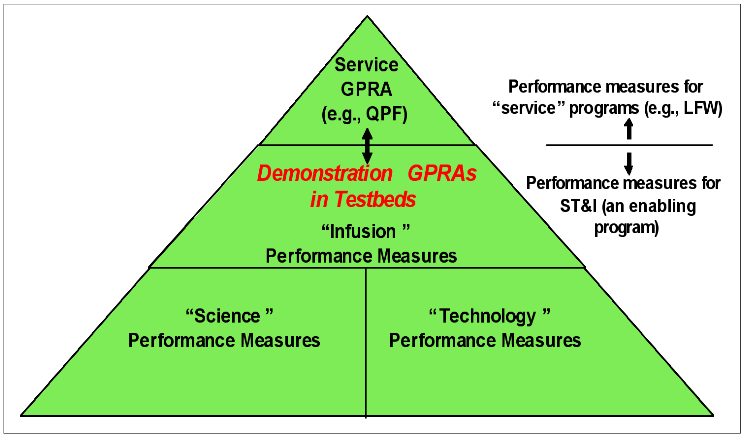


Figure 1.1 A graphical depiction of the relationship between S&T performance measures, the transitional demonstration (or stretch) measures, and formal GPRA metrics.

Figure 1.2 Forecasting water correctly and incorrectly impacts society and appears in the local and national news every day.

• Researchers and forecasters jointly define strategies to demonstrate impacts on the suitable "Demonstration GPRA" goal (e.g., QPF) during the tests

• If tests show regional improvement, extend results nationally with follow-up testing

1.2 NOAA and the Nation's Water Resources

Forecasting water is central to NOAA's mission and is of great societal impact as is evidenced by headlines that are routinely in the news (Figure 1.2) and by the significant number of socio-economic disasters that involve fresh water. These provide a focus for NOAA's emphasis on water-related, high-impact events (Figure 1.3).

Examples of the many ways that NOAA's water activities impact society and commerce include a variety of meteorological observation and numerical weather and river flow prediction modeling systems (Table 1.2).

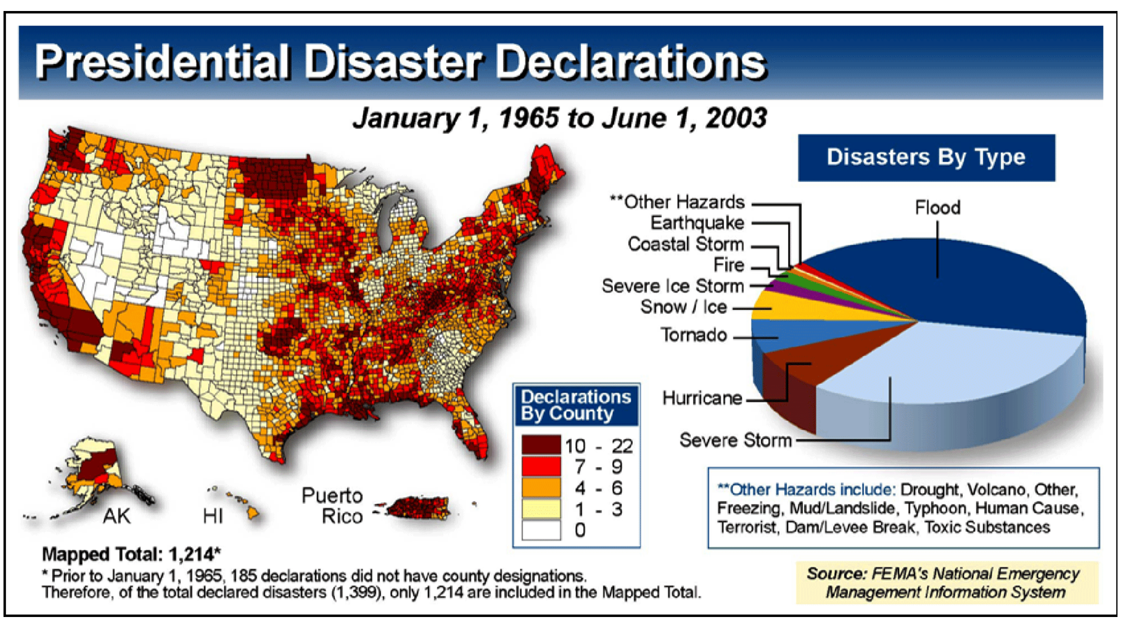


Figure 1.3 Over 80% of Presidential Disaster Declarations from 1965 to 2003 were related to some form of water hazard including floods, severe storms, and snow/ice events.

Table 1.2 Examples of NOAA's Water Monitoring and Forecasting Systems

River and Stream Forecasts (NWS)	• Precipitation and snow pack • Flash floods • Streamflow • Water supply • Warnings and assessments
Great Lakes (OAR)	• Water levels • Ice conditions • Hazardous spill response
Major Bays and Ports (NOS)	• Water levels • Currents • Storm surge
Numerical Weather Prediction (NWS, OAR)	• Precipitation • Data assimilation • Mesoscale models
Research and Development (OAR, NWS, NOS, NESDIS)	• Observations • Land surface conditions • Data management • Hazards assessment • Coupled modeling systems

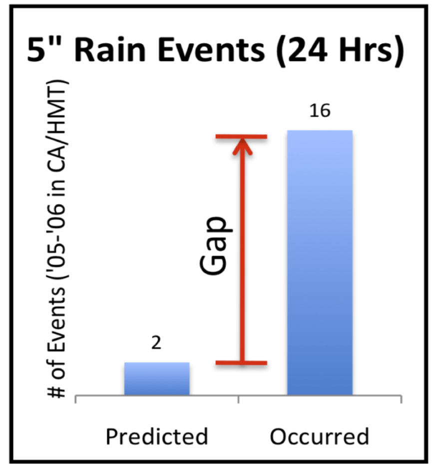


Figure 1.4 During the 2005-2006 HMT season, sixteen extreme events occurred, yet only two were predicted. This is one of the key results from the HMT verification work, which is described in detail in section 4.

In many cases, precipitation is the single greatest hydrologic forcing factor. While NOAA has made great strides in forecasting precipitation, extreme events remain a particular challenge. For example, in one year in California during the HMT (Figure 1.4), sixteen "extreme" [1]events occurred, yet only two were correctly predicted.

Precipitation appears to be at the foremost of peoples concerns. In a nationwide survey, Lazo et al. (2009) found that:

> *"... precipitation and temperature information are the most important self-reported components of forecasts to respondents."*

In fact, overall, out of fourteen different categories of information, six of the top seven were concerned with aspects of precipitation. The respondents' responses rated "when precipitation will occur", the "chance of precipitation", and "where precipitation will occur" as the top three most important components in a weather forecast, in that order, with "high temperature" (ranked fifth) being the only non-precipitation component in the top seven.

1.3 NOAA's Water Guidance and Calls to Action

NOAA has developed a number of high-level management documents, which provide guidance to efforts for improving forecasts of water-related issues (Table 1.3). These documents range from the fundamental charge for weather forecasting in the NWS Organic Act and the Inland Flood Forecasting and Warning Act. Several guidance documents emphasize the strategies for Regional Collaboration and the Hydrometeorology Testbeds (see section 2 for details on how the HMT addresses the regional deployment emphasis of these guidance documents).

1 For these purposes, an extreme event was defined as five inches of rain, or more, in a 24-hour period.

Table 1.3 NOAA Makes Fresh Water a Priority: Guidance to Forecast Water

NOAA's NWS Organic Act

The forecasting of water is mandated in the NWS Organic Act which states, "…forecasting of weather, the issue of storm warnings, display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers…"

NOAA's Inland Flood Forecasting and Warning Act

Forecasting of water also appears in the NOAA Inland Flood Forecasting and Warning Act: "…improve the capability to accurately forecast inland flooding, and conduct research, outreach, and education activities regarding the dangers and risks associated with inland flooding…"

NOAA's NWS Hydrology STIP (2002)

NOAA's NWS Hydrology Science and Technology Infusion Plan (STIP) identifies hydrometeorology testbeds as a means to address key R&D needs before technology can be infused into operations.

NOAA Creates Weather and Water Goal (2003)

Science Technology & Infusion Program defines Water Resources R&D Capability (HMT), 2004

NOAA's NWS-OAR Summit (August 2006)

One of the outcomes from the NWS-OAR Summit held in August 2006 was to identify the goal of generating support for testbeds to transfer technology from Research to Operation (R2O) and from Operation to Research (O2R).

NOAA's Regional Collaboration (2007)

NOAA's Regional Collaboration strategy has four crosscutting priority areas: HMT is a key activity of the Integrated Water Resource Services priority area.

VADM Lautenbacher Underscores the Importance of Fresh Water as a NOAA Priority (October 2008)

VADM Lautenbacher's parting email notes: "The ability to provide clean, safe and available water - the single largest challenge for a world with expanding population and a changing climate - must play a unifying role within the NOAA organization and have the highest priority for NOAA's leadership goals in interagency programs and integration. Bringing all the parts of the water cycle together in research and operations to provide sound science for developing national and worldwide water policies is another organizational challenge that I look forward to seeing NOAA tackle."

NOAA's Annual Guidance Memorandum for FY 2010–2014

In the NOAA Annual Guidance Memorandum for FY 2010 – 2014, two of the six Environmental Data and Information Services Priorities focus on water and the forecasting of water. The memorandum is in Appendix A and the two water topics are:

- "High-impact weather and water events"
- "Water information services"

1.3.1 NRC Report: Flash Flood Forecasting over Complex Terrain

The HMT addresses a recommendation made by a recent National Research Council report (NRC 2005) on deployment of NEXRAD radars. The report responded to concerns that NEXRAD radars are designed for long-range coverage and can be insufficient due to terrain-induced blockage at low altitudes. The report noted that some of these problems can be resolved by deploying additional radars, which could be smaller, cheaper, and more easily (and even adaptively) deployable than NEXRAD. This is what the HMT is doing through deployment of "gap-filling" radars, which are able to detect local severe weather conditions in areas of complex terrain. The report also recommended that the NWS continue its efforts to develop and evaluate hydrologic and coupled meteorological-hydrologic models. HMT is doing this to advance technologies useful for improved flash flood guidance and warnings. HMT has deployed the polarimetric radar modification to improve the data quality and quantitative precipitation estimation (QPE) measurement capabilities of NEXRAD. HMT has deployed real-time data assimilation systems that incorporate observations into high-resolution mesoscale numerical models to provide rapidly updated wind and precipitation forecasts. HMT is demonstrating data fusion systems that incorporate all available observation datasets together with numerical model output to produce very short-range (0- to 2-h), site-specific forecasts. These advances are producing improved forecasts, including ensemble and probabilistic forecasts, of precipitation rate and accumulation that are essential for flash flood forecasting.

1.3.2 NRC Report: NOAA and the Global Precipitation Measurement (GPM) Mission

Another NRC report (2007) "NOAA's Role in Space-Based Global Precipitation Estimation and Application" recommends for NOAA HMT: *"There will be a symbiotic relationship between GPM and the Hydrometeorological Testbed. The Hydrometeorological Testbed will use GPM data as an additional input for experimentation and demonstration, and GPM will obtain validation elements from the Hydrometeorological Testbed."*

1.3.3 NRC Report: Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks

The recent NRC report (2009) makes the following recommendation regarding testbeds, in the context of the nation's mesoscale observational capabilities, which "are highly variable in quantity, quality, accessibility, instrument set, site selection, and metadata." The report makes a further call for testbeds, such as HMT, in the following recommendation: *"Federal agencies and partners should employ testbeds for applied research and development to evaluate and integrate national mesoscale observing systems, networks thereof, and attendant data assimilation systems. Among other issues, testbeds should address the unique requirements of urbanized areas, mountainous terrain, and coastal zones, which currently present especially formidable deficiencies and challenges."*

1.3.4 AMS Call to Action

The need to understand and forecast water is clear in an AMS Policy Statement on Water Resources in the 21st Century: *"The provision of adequate freshwater resources for humans and ecosystems will be one of the most critical and potentially contentious issues facing society and governments at all levels during the 21st century. Water is fundamental to our lives … Water resource managers face daunting challenges with population growth and migration, land use changes, and pollution locally, nationally, and globally — problems likely to be exacerbated over the next several decades by climate change. In light of this developing water crisis, the American Meteorological Society (AMS) issues this statement as a call to action."*

1.4 HMT History

The first regional testbed in the national strategy, HMT-West, was established in the American River Basin near Sacramento, CA in 2005. However, the HMT concept evolved from a series of experiments known as CALJET and PACJET projects dating from 1997–2003 centered on the Pacific Coast (primarily around the Russian River Basin). While productive from a research standpoint, the CALJET and PACJET experiences also suggested a need for a new model to better engage operational communities in the research process. This transformation from a conventional research paradigm to a hydrometeorology testbed program, was fostered by a more formal recognition of the need for a better process to improve NOAA's capabilities to monitor and predict precipitation and runoff in the community at large. For example the USWRP held a workshop on QPF and called for a Hydrometeorology Testbed (Dabberdt et al. 2005a).

From this, preliminary, small-scale tests of prototypical HMT facilities were conducted in California's Coast Range in 2004 (Russian River Basin; "HMT-04") and subsequently HMT moved to the western slopes of the Sierra Nevada for a second prototype testbed during the winter of 2004–2005, where the focus became the American River Basin (ARB) located between Sacramento and Reno[2]. Water from the American River Basin is a critical resource for California's economy and natural ecosystems, and the threat of flooding poses an extremely serious concern for the heavily populated downstream area (Figure 1.5; an early conceptual

2 Note that while the focus shifted to the ARB, the sites in the Russian River Basin have been operated since, yielding a valuable climatology extending back for more than a decade.

rendering of the ARB testbed). The frequent impact of prolonged, heavy winter precipitation from concentrated "atmospheric rivers" of moisture, originating in the tropical Pacific, underscores the area's flood vulnerability. In fact, the Sacramento region is considered to be among the nation’s most at-risk communities due to severe flood threats (second only to New Orleans).

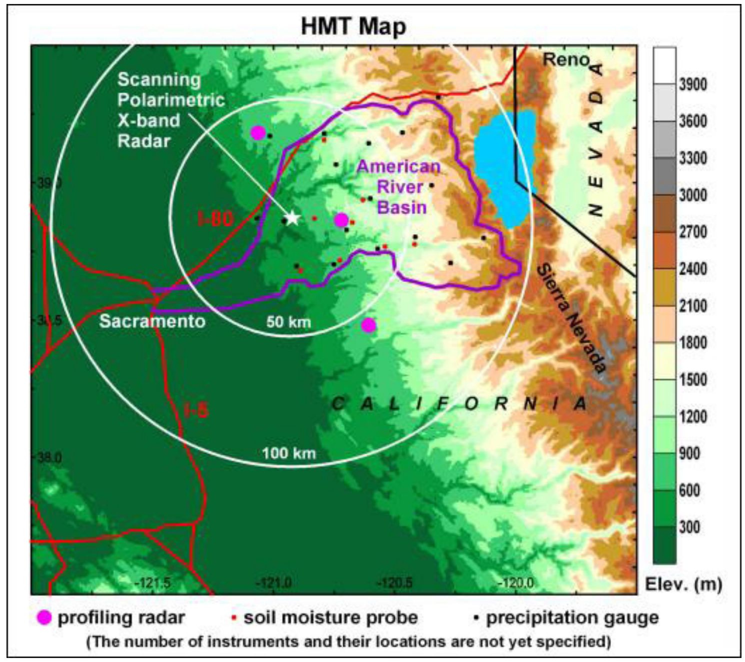


Figure 1.5 An early conceptual basin scale map of HMT-West illustrating the proximity of the American River Basin to the flood-prone Sacramento area.

The first full-scale deployment of HMT occurred during the winters of 2005–2006 (HMT-West 2006). With each subsequent year, the testbed was improved based on lessons learned from the previous season, and additional resources were also brought to bear, thus growing the testbed considerably from its initial beginnings. Presently, the HMT-West 2009 season is the fourth and most comprehensive deployment in the American River Basin to date, and intense field operations in HMT-West are scheduled through at least 2010. Figure 1.6 graphically depicts this evolution and ramp-up of the testbed from its CALJET-PACJET origins. As the HMT Program evolves, the HMT-West Project will transition to a legacy mode, with an ongoing, but reduced level of activity as other testbeds are established.

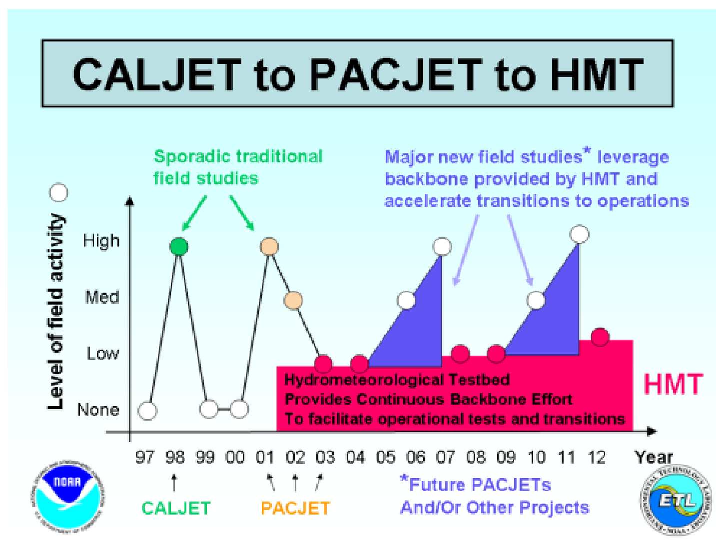


Figure 1.6 A graphical depiction of the origins and evolution of the NOAA Hydrometeorology Testbed.

A component of the HMT was established at the NCEP Hydrometeorological Prediction Center (HPC) in August 2005. Its collocation with HPC forecast operations facilitates R2O operations through the interaction of HPC forecasters and visiting scientists with the HMT staff. HMT at HPC has worked closely with the HMT-West and HMT-Southeast (planning) regional projects, leading to the incorporation of several methodologies from HMT-West into HPC operations. The HPC component of the HMT also works with other NOAA components and the academic community to identify additional candidates for R2O.

Table 1.4 provides a tabular look at the history of the HMT, and includes reference to the key planning activities, meetings and milestones leading to the current state. Future plans and activities are addressed in the following section.

Table 1.4 History of HMT activities.

Date	Location	Event
June 15–17, 2009	Chapel Hill, NC	HMT-SE Research Planning Workshop
February 3–5, 2009	Chapel Hill, NC	HMT-SE Operational Needs & Requirements Workshop
December 2008 to March 2009	American River Basin, California	HMT-West 2009 Field Deployment, Building on HMT-West 2008 Deployment
November 13-14, 2008	Boulder, CO	HMT Mini-Workshop on FFMP
May 22–23, 2008	Sacramento, CA	Annual Meeting of the HMT Advisory Panel
May 20–21, 2008	Sacramento, CA	HMT Research to Operations (R-to-O) Workshop
December 2007 to March 2008	American River Basin, California	HMT-West 2008 Field Deployment, Building on HMT-West 2007 Deployment
June 2007	Sacramento, California	Meeting of HMT Advisory Panel [pdf]
December 2006 to March 2007	American River Basin, California	HMT-West 2007 Field Deployment, Building on HMT-West 2006 Deployment
September 2006	National	Full-time HMT Project Manager Appointed
June 2006	Sacramento, California	Third NOAA HMT Planning Meeting [pdf]
December 2005 to March 2006	American River Basin, California	HMT-West 2006 Field Deployment, First full-scale deployment for HMT-West
August 2005	Camp Springs, MD	Establishment of the NCEP HPC component of the HMT
March 2005	Washington, D. C.	Second NOAA HMT Planning Meeting
December 2004 to March 2005	American River Basin, California	HMT-West 2005 Field Deployment, Preliminary deployment for HMT-West
December 2003 to March 2004	Russian River Basin, California	HMT-2004 Field Deployment, More Refined HMT Prototype
December 2002 to March 2003	Russian River Basin, California	PACJET-2003 Field Deployment, First HMT Prototype
November 2002	Washington, D. C.	First NOAA HMT Planning Meeting [pdf]
December 2001 to March 2002	Offshore and along the Washington, Oregon and California coastlines--base of operations in Portland, Oregon	PACJET-2002 Field Experiment
October 2001	Monterey, California	Workshop with West Coast operational forecasting and forecast end-user communities [pdf]
December 2000 to March 2001	Offshore and along the California, Oregon and Washington coastlines--base of operations in Monterey, California	PACJET-2001 Field Experiment
September 1999	Monterey, California	Workshop with West Coast operational forecasting community
December 1997 to March 1998	Offshore and along the California coastline—base of operations in Monterey, California	CALJET Field Experiment

1.5 HMT Accomplishments

The HMT has evolved into an impactful program. To date, HMT has:

- Created a critical mass of research effort on one of meteorology's toughest challenges — QPF
- Created partnerships between organizations within OAR and with NWS
- Brought additional resources to bear on this mission-critical problem of precipitation
- Generated new tools and physical understanding that are being transitioned into NWS operations
- Served as an effective environment to develop and demonstrate prototypical systems

While section 4 delves into the details of recent and current activities in HMT, the remainder of this section endeavors to provide a high-level summary of HMT's achievements to date.

1.5.1 Scientific & Technical Accomplishments

HMT has contributed to significant advances in our understanding of processes leading to extreme rainfall in complex terrain. In particular, HMT has:

- Documented and characterized atmospheric river structure and its importance to flooding and water supply; and has identified associated moisture flux thresholds leading to heavy precipitation
- Quantified non-bright-band rain, which produces ~25-35% of total precipitation in key areas and yet is very shallow, often beneath the current radar coverage
- Developed a technique using normalized anomalies of precipitable water and moisture flux fields, as predictors of extreme precipitation

A *Coastal Atmospheric River Monitoring & Early Warning System* has been developed. This system integrates state-of-the-art observations and modeling to provide a tool to monitor, predict and diagnose atmospheric river enhanced precipitation, and:

- Uses advanced observations to monitor conditions
- Uses specialized, high-resolution models for forecasts
- Uses thresholds derived from scientific work on ARs for:
    - Low-level winds (observed by wind profilers)
    - Vertically integrated water vapor (from GPS-Met)
    - Derived “bulk moisture flux” threshold (combines GPS-Met and profiler observations)
- Is available in real time

HMT has developed state-of-the-art precipitation analyses in complex terrain, utilizing both standard and polarimetric radar observations; surface gauge data; and specific vertical profile of reflectivity (VPR) adjustments to correct for the bright band. These methodologies are required for:

- DMIP-2 evaluations of various streamflow models; including and especially next- generation distributed hydrologic models
- Verification of high-resolution QPF in complex terrain

There have also been a number of observing system technology advances, including:

- The development of low-cost, snow level radar
- The invention of atmospheric river observatories (AROs)
- Creation of a transportable ARO
- Deployment of level loggers for stream depth (University of Washington-led)
- Deployment of unique temperature sensor array (University of Washington-led)
- Development of soil moisture measurement network methodologies
- Automated rain sampler for isotope measurements (USGS-led); used to ascertain the origin and history of precipitation
- Development of advanced radar techniques, including polarimetric QPE algorithms; polarimetric attenuation correction algorithms (for X-band radars); and VPR techniques to account for bright-band contamination and/or beams in the snow above the bright band

Additionally, a number of observing system assessments have been conducted, leading to evaluations of:

- The ability of the COSMIC satellite to measure AR conditions offshore (including profiles of moisture)
- A new integrated IWV satellite product, which allows better tracking of ARs (useful for QPF)
- Integrated ocean observing system evaluations of coastal profiler technology
    - 915 MHz versus 449 MHz profiler with RASS
- Polarimetric radar testing (helps in preparation for dual-pole implementation on NEXRAD)

HMT research has shown that most extreme rainfall events on the West Coast are associated with ARs. Building on a variety of developments through HMT, a "Pacific Atmospheric River Threat Index" (PARTI) is under development. The PARTI will combine offshore (i.e. satellite) and/or near-shore observations with data from numerical weather prediction models, to provide a quantitative assessment of the risk for extreme precipitation. The prototype being developed, is analogous to current hurricane practices; the PARTI will give a numeric measure of risk (an index), as well as an indication of which areas are most likely to be affected and when.

HMT has led to the development of prototype, or demonstration, performance measures: these measures provide:

- A new measure for extreme QPF: Current verification of precipitation forecasts to not adequately account for extreme events. Initially developed on the West Coast, the technique is now applicable across the entire United States.
- A new measure to track snow level forecasts: In complex terrain, small changes in the elevation at which rain turns into snow, can produce significant changes in runoff. Prior to this, a performance measure for snow level forecasts did not exist.

Peer-reviewed publications are an important metric of success in any scientific endeavor, and they provide both documentation of and credibility to the effort. To date, there have been forty-four HMT-related peer-reviewed journal articles published since the year 2000. Appendix B provides an analysis of the growing body of literature that comprises the HMT bibliography.

1.5.2 Transition to Operations & Training

Now in the fourth full year of operations, the HMT has produced a number of transition projects that are underway or are being initiated. A number of these have been enabled through the EFREP partnership with the State of California, which sought to implement key findings from HMT. They include:

- Installation of new GPS-Met sites
- Installation of soil moisture networks
- A snow level radar network
- The deployment of the a scanning radar system by the KPIX television station in San Francisco (driven by results from a NOAA gap-filling radar demonstration on the coast, north of San Francisco)
- A mesoscale ensemble modeling system (distributed local modeling), providing basin scale, probabilistic forecasts of QPF
- A decision support tool for extreme QPF
- A Pacific Atmospheric River Threat Index (PARTI): a decision support tool, incorporating observations and model information providing guidance on the severity and land-falling track of atmospheric rivers
- Normalized water vapor flux anomalies for extreme QPF
- TIGGE ensemble QPF effort
- Enabling DMIP-2 activities, through state of the art QPE products
- Establishing new performance measure for extreme QPF
- Establishing new performance measure for snow level

There have also been a number of NRC reports and articles published in the Bulletin of the American Meteorological Society intertwined with HMT — i.e., either using or recommending HMT results, concepts or approaches.

NRC:

- *Flash Flood Forecasting Over Complex Terrain: With an Assessment of the Sulphur Mountain NEXRAD in Southern California* (2005)
- *NOAA's Role in Space-Based Global Precipitation Estimation and Application* (2007)

- *Observing Weather and Climate From the Ground Up: A Nationwide Network of Networks* (2009)

BAMS:

- *Improving short-term (0-48 h) cool season quantitative precipitation forecasting: Recommendations from a USWRP workshop* (Ralph et al. 2005)
- *Improving Quantitative Precipitation Forecasts in the Warm Season: A USWRP Research and Development Strategy* (Fritsch and Carbone 2004)
- *Multifunctional Mesoscale Observing Networks* (Dabberdt et al. 2005)
- *Research: The Helsinki Mesoscale Testbed: An Invitation to Use a New 3-D Observation Network* (Dabberdt et al. 2005a)
- *Joint NOAA/NWS/USGS Prototype Debris Flow Warning System for Recently Burned Areas in Southern California* (Restrepo et al. 2008)

1.5.3 Programmatic & Organizational Accomplishments

The creation of HMT (as outlined in the previous section) is, in and of itself, a significant accomplishment: it represents one bridge across the gulf between operations and research. In the process of establishing the testbed, HMT strengthened ties between NOAA Line Offices and played an enabling role in a number of programmatic areas:

- The American River Basin was selected for testing of next generation hydrologic models within the NWS/OHD-led Distributed Model Intercomparison Project-2 (DMIP-2) based on the recognized need to address conditions with complex terrain and snow, and the fact that HMT was being implemented on the American River and would provide unique "forcing" data for the testing of many models from the broader hydrologic community:
- An OAR-NWS/OHD partnership was established on state-of-the-art hydrologic forcing data sets (precipitation, soil moisture and temperature, etc.) from HMT for DMIP-2
- USWRP investments in QPF:
    - Develop new performance measure for extreme QPF
    - Provide grants via CSTAR for QPF
    - Provide grants leveraging NASA-NOAA Global Precipitation Measurements (GPM) Mission
    - Creates new focus at DTC on QPF in partnership with HMT
- HMT-West has triggered other regional efforts within HMT:
    - Mini HMT-Arizona soil moisture and temperature network operational Mini HMT-Upper Colorado soil moisture and temperature network is being deployed
    - HMT-Southeast actively being planned
    - HMT-Northwest being considered
- HMT has helped elevate water resources research and forecasting as a NOAA Priority:
    - IWRS Priority Area established for all of NOAA
    - Integrated Water Forecasting Program created within W&W
- HMT has created a long-term approach to linking research and operations:
    - Redirected OAR lab base to focus long-term on precipitation
    - Built partnerships between OAR's weather labs
    - Established a management system involving OAR and NWS
- The traditional research field experiment had one major field season. HMT has established a new approach:
    - HMT is multiyear, rather than the typical 1–3 month duration
    - Instead of having everyone continuously in the field, HMT developed a forecast-based strategy for sending staff into the field only when weather conditions were suitable (captured 90% of the events at less than half the typical cost)

- HMT uses field equipment that is mostly unattended and thus less expensive
- SHARE experiment designed and proposed to NSF
- Debris flow prediction pilot study built on HMT-W experience, tools and teams
- CalWater experiment to determine the impact of aerosols on precipitation and the role of atmospheric rivers in water supply and flooding (sponsored by NOAA and California Energy Commission)
- The California Department of Water Resources, Enhanced Flood Response and Emergency Preparedness (EFREP) project is implementing key results and findings from HMT in CA (an HMT Legacy activity)
- ARkStorm emergency preparedness scenario being developed with USGS
- NOAA's UAS project is testing applications for west coast storms and associated atmospheric rivers
- NOAA UAS project is sponsoring development of a dropsonde capability for NASA's Global Hawk partly to monitor ARs in connection with HMT

1.6 Lessons Learned from HMT-West

The HMT-Southeast planning process has benefited from the "lessons learned" in HMT-West. These lessons about developing and executing a testbed are summarized below:

- Seek to gain a clear vision for a successful outcome up front, and firmly control testbed activities from the beginning, with a clear connection to operations defined for each activity – i.e. how that information would potentially be utilized and what specific deliverables may result
- Establish performance metrics and clear baselines for improvement
- Staff involvement and buy-in at the operational level are very important for success, so they should be involved early i.) to help identify where improvements are needed and current performance baselines; ii.) to vet proposed testbed activities; iii.) and to engage the operational staff in the instrument deployments and experimental design, etc., whenever/where possible
- Frequently re-evaluate progress and the viability of existing subprojects, don't hesitate to cease efforts when circumstances dictate
- Keep a focused scope and don't be tempted to overreach: it is better to do a few things well than to take on overly ambitious projects
- As appropriate, concentrate or focus on the observational network, targeting specific basins
- Transition issues have been HMT's biggest challenge – a "Research-to-Operations (R2O) Workshop", held in May, 2008 was a very important follow-up activity, allowing us to weave insights/successes from HMT-West into operations
- A long-term (multiyear) commitment is required to allow the research and development cycle to mature and for sufficient demonstration efforts to be conducted
- While daily communications are important during field operations, calls should be kept focused and of minimum duration. Interesting or otherwise important cases should be debriefed within a short period of time after an IOP concludes. Scientific staff should visit NWS field offices during operations to gain an understanding and appreciation of operational pressures and procedures. Focused "mini workshops" (with a dozen or so people), have been an effective method of exchange between research and operations staff
- Engaging other federal partners, state and local agencies and stakeholders has been important to the success of HMT

2 HMT Science Plan & Management

2.1 Goals and Objectives

HMT is founded on the vision that a water-aware public will benefit from improved water resource services. One aspect of the HMT mission is to demonstrate that the development and regional deployment of advanced sensors and monitoring technologies, coupled with numerical models and decision support systems, can improve NOAA's capacity for providing earlier and more accurate forecasts. These forecasts would yield increased flood warning lead times and result in better water resource management and drought mitigation.

The general goal is to develop, test, and demonstrate new methods and tools that improve NOAA's hydrometeorological services, including quantitative precipitation estimation (QPE) and forecasting (QPF), streamflow predictions, flood warnings and drought monitoring. Those prototypes that prove effective in focused demonstrations, both technically and practically, are then transitioned into NOAA forecast operations and information services. Accurate, high-resolution precipitation and soil moisture information are common denominators required for each of these services and they represent a major focus of HMT, along with improved understanding of the physical processes governing precipitation.

HMT yields research findings and field-tested methods that can be implemented into NOAA's operational forecast and information services. These include improved algorithms, better models, new observations or better use of existing observations, and forecaster training modules describing new tools or physical understanding. A key output of HMT is an accurate description of the spatio-temporal distribution of precipitation over carefully selected pilot study watersheds. These observations are then used to evaluate existing and new forecast models (e.g., the WRF model; being developed for use at ERSL, NCEP and elsewhere) and other forecast tools (e.g., Mountain Mapper; used at River Forecast Centers to downscale NCEP/HPC's QPF products over mountains), as well as those needed for the NWS Watch-Warning System (e.g., QPE SUMS; being tested at River Forecast Centers) and streamflow forecasting system (e.g., DMIP; a study to assess candidates for NOAA's next-generation streamflow forecast model).

HMT is linked to research activities external to NOAA, including partners in Joint Institutes, such as the "Water-in-the-West" effort at CIRES, and through interagency partners such as in the USWRP (e.g., the USWRP Cool-Season QPF Implementation Plan identifies the establishment of a national HMT infrastructure at NOAA as a leading priority). Two other examples where NOAA is extending its suite of services are the development of water quality forecasts (jointly with EPA) and a debris flow watch-warning system (jointly with USGS). A common denominator of these needs is the requirement for accurate water quantity information, a need that HMT helps NOAA meet.

The HMT payoffs include:

- Accelerated development of those prototype methods and tools that hold the greatest promise to improve NOAA's hydrological and hydrometeorological services
- Pilot studies to accelerate the transition of proven methods into forecast operations and information services. The tests and demonstrations are planned and conducted jointly by research and operations partners, in collaboration with external forecast users.
- Improvements in scores on NOAA's operational Government Performance Requirements Act (GPRA) goals in QPF and flood warnings, after a transition to operations
- New or improved baselines and performance measures to provide a more accurate assessment of NOAA's ability to monitor and predict precipitation and runoff.
- Socio-economic benefits accrued through improved decision making, e.g., better QPF can help

reservoir operators balance flood control against competing needs for water resources. Development of forecast-based reservoir operations on one key watershed alone is projected to save 60,000 acre feet of water for later use, without compromising flood control.

2.1.1 Goals

The primary goals of the HMT Program are to:

- Provide a foundation of technology and experience that will improve NOAA's capabilities for flood warnings and water management
- Evaluate the viability of advanced technologies deployed at the regional scale for precipitation estimation and forecasting
- Demonstrate the effectiveness of coordinated multiagency operations (federal, state and local) for flood warnings and water management
- Create a framework so that interdisciplinary and inter- and intra-agency collaborative research and demonstration can be conducted

2.1.2 Objectives

Specific objectives of the HMT Program are derived from the major activity (or application) areas, and include the following:

- Quantitative precipitation estimation (QPE)
    - Provide a more complete picture of extreme precipitation events through deployment of an expanded rain gauge network, a disdrometer network, profiling and scanning radars, and implementation of intensified upper-air observations
    - Test new methods for deriving precipitation from more commonly available remote observing platforms
    - Determine the impact of these QPEs in hydrologic models
- Quantitative precipitation forecasts (QPF)
    - Develop and demonstrate procedures for high spatial and temporal resolution ensemble mesoscale models covering the HMT operations domain
    - Determine the impact of these QPFs in hydrologic models
    - Deploy and evaluate methods for remote access to large data sets across NWS and partner agencies
- Snow Level and Surface Snow Information
    - Characterize snow level (SL) and snow-water equivalent (SWE) to help deal with the issues of hydrometeorological forecasting, water management, and flood control
    - Design and deploy advanced sensors for snow level (SL) nowcasting and forecast verification
- Hydrologic Application
    - Provide hydrologic evaluation of advanced observations of rain and snow, temperature, soil moisture, and other variables in the context of real-time operational forecasting at CNRFC
    - Provide a venue to address broader science questions for hydrologic forecasting in mountainous areas based on R&D in the North Fork American River, including the Distributed Model Intercomparison Project – Phase 2 (DMIP-2)
    - Support the Integrated Water Resources Services (IWRSS) project in Arizona through deployment of soil moisture and meteorological sensors.
    - Provide HMT QPF and other data sets to the southern California WFOs Flash Flood Monitoring Program (FFMP) in support of debris flow warnings in fire burn areas
- Debris Flow
    - Provide HMT enhanced QPE, QPF and associated observations and high-resolution modeling

products to support debris flow guidance for the FFMP application

- Verification
    - o Develop and apply verification methods that allow quantifiable assessments of improvements in forecast skill for QPF, hydrologic, and snow level forecasts
    - o Develop baseline performance measures of precipitation and related processes
- Decision Support Tools
    - o Demonstrate the efficacy of decision support tools placed in actual forecasting and hazardous event warning operations. This category of HMT activities includes:
        - Flash Flood Monitoring and Prediction (FFMP)
        - Forecaster Workstation Upgrades Using Advanced Linux Prototype System (ALPS)
        - Gridded Forecast Editor (GFE)
        - Integrated Water Resources Science and Services (IWRSS)

2.2 Implementation Strategy

The success of HMT depends on the quality of research conducted, the number and quality of publications and reports produced (thus building credibility), and the number of systems prototyped and demonstrated in an operational setting. HMT also seeks to transfer and integrate this leading edge technology and understanding from NOAA's research centers to NOAA's operation centers. While many aspects of this transfer remain beyond the control of HMT's partners, HMT will endeavor to facilitate and enable this process.

Thus the research-to-operations (R-to-O), and related operations-to-research (O-to-R), paradigm is the backbone of HMT's Implementation Strategy. The scope of this effort engages expertise that resides both within NOAA Research and the National Weather Service and outside of the immediate NOAA community.

2.2.1 Building Partnerships Across NOAA

ESRL provides the home base for HMT with major involvement of the Physical Sciences Division (PSD) and the Global Systems Division (GSD).

- Physical Sciences Division: QPE, QPF, observing systems, model diagnostics, physical processes, Weather-Climate Connection, extreme events research and microphysics
- Global Systems Division: Data assimilation and coupling with models

HMT integrates ESRL capabilities in the following areas: use of experimental field data to diagnose errors in operational models, forecaster training, observing systems, mesoscale numerical modeling, and weather-climate connections.

The diversity of talent and expertise across NOAA is being harnessed in HMT by building partnerships that break down traditional 'stovepipes'. The problems that HMT addresses require creative thinking with innovative solutions. The cross-discipline structure of HMT includes researchers and forecasters talking on equal ground and overcoming constraining administrative structures to achieve new working relationships that are time efficient and effective in realizing improved water services.

Other partners in OAR, NWS, and NESDIS complement and enhance ESRL capabilities. There is a critical need for coordination of these diverse capabilities and roles across NOAA. The existence of HMT as an integrating theme at ESRL helps fill this gap, through both leadership and technical expertise, and provides an important capability to help NOAA address the critical area of water resources.

Examples of building partnerships across NOAA are summarized below. Of primary significance are the strong partnership relations established with the NOAA agencies charged with operations responsibilities – the River Forecast Centers (RFC) and Weather Forecast Offices (WFO)

- NOAA Coastal Services Center (CSC)
- NWS Office of Hydrologic Development (OHD: Leadership on hydrology research and system development (CHPS), Distributed Model Intercomparison Project (DMIP), Debris Flow Program
- NWS NCEP/Hydrometeorological Prediction Center, Environmental Modeling Center: QPF, including precipitation amount and type
- NWS OCWWS: Snow cover, and hydrometeorology requirements
- NWS OST: FFMP and debris flow
- NWS Western, Eastern and Southern Region Headquarters: for regional coordination
- NWS California/Nevada River Forecast Center: QPE/QPF, observing system and decision support evaluation
- NWS Monterrey, Sacramento, Reno, and Eureka WFOs: Watch-warning program/flash flooding, QPE/QPF, observing system and decision support evaluation
- NESDIS: Satellite data records for model initialization: clouds, radiation, ice phase
- National Severe Storms Lab: QPE, observing systems

Matrix Planning
Coordination within NOAA, is facilitated by NOAA's Planning, Programming, Budgeting, and Execution System (PPBES). HMT resides within the Weather & Water Goal, Science, Technology and Infusion (ST&I) Program. These programmatic activities have been coordinated with the Integrated Water Forecasting (IWF, formerly Hydrology) Program and with a mutual awareness of the Local Forecasts and Warning Program.

Regional coordination has occurred through the NOAA Integrated Water Resource Services-Priority Area Task Team (IWRS-PATT), and more recently with the Southeast and Caribbean Regional Team (SECART).

2.2.2 The HMT Concept: Testbed as a Process

The HMT concept consists of a process of continuously iterating around a test and refinement loop as diagramed in Figure 2.1, to improve and eventually make new methods operational. This embodies the R-to-O, O-to-R philosophy articulated above. The test and refinement loop includes these steps:

- Develop and introduce new ideas, data, etc.
- Experiment, prototype, and demonstrate
- Verify
- Assess impact
- Revise and iterate the "good"; terminate some activities*

Ultimately, the outputs of the testbed process are methods or technologies that can be put into operation by NWS, NOS, OAR, and state and local agencies. *Note that there are a number of reasons why an activity should be ended, such as reprioritization of resources, cost-effectiveness, feasibility, negative results, or when a new solution presents itself and replaces old capabilities, etc. This applies to both research and to operations.

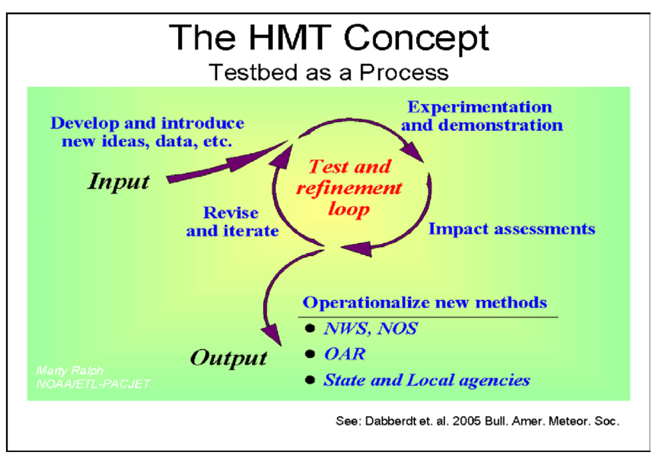


Figure 2.1 Testbeds are a process to get ideas off of the drawing table and into operations (Dabberdt et al. 2005b). This feedback process encapsulates both the R-to-O and the O-to-R aspects of this problem.

2.2.3 National Testbed Strategy with Regional Implementations

Each region of the country is characterized by unique hydrometeorological issues and therefore poses unique challenges. NOAA has more generally embraced this concept of regional environmental issues through its Regional Collaboration effort and crosscutting task teams (http://www.ppi.noaa.gov/PPI_Capabilities/regional_collaboration.html). However, with limited resources, it is not possible to address all of the regionally driven hydrologic forecasting problems facing the nation simultaneously. Therefore, the HMT Program is a *national testbed strategy* with *regional implementation* of testbed projects.

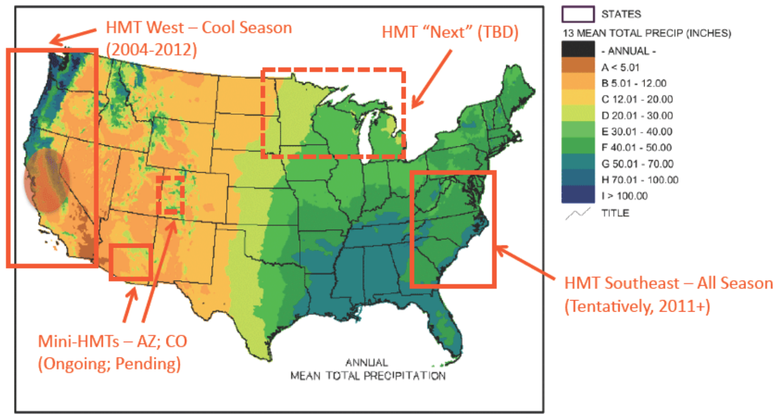


Figure 2.2 The HMT Program is a national testbed strategy that is being implemented through regional testbed projects across the U.S.

In practice, this means that resources are focused in one, representative region of the country to solve the hydrometeorology problems in that region for several years. Then, the focus is shifted to another region of the country while maintaining a continued (or legacy) effort in the original focus region. The legacy mode of testbed operations ensures that there is cross-pollination between testbeds and helps to facilitate transitions to operations. Figure 2.2 shows a map of the U.S. identifying three focus Projects: HMT-West, HMT-Southeast, and HMT-"Next". The HMT-West region has been defined and the ongoing operations have been conducted for several years. The HMT-Southeast project is currently in the planning phase, and will be located in the region anchored by the Carolinas (e.g. the Tar and the Neuse River Basins in North Carolina); and the HMT-"Next" Project is presented in the north-central US to illustrate the concept, but the specific region of this testbed remains to be determined.

2.2.4 Other Partnerships and Interagency Synergism

The partnership approach is extended to other federal, state, and local agencies. For example, on the federal level, HMT-West has developed working relations with the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation who are the primary agencies charged with operations of the major reservoirs in the Sacramento River Basin. The Folsom Dam and reservoir is the primary flood control facility located on the American River just upstream of Sacramento, CA. Partnerships are now being established in the Southeast as well. In addition to the aforementioned, some of the key external collaborations that have been established are:

- California Department of Water Resources (DWR)
- California Energy Commission (CEC)
- Renaissance Computing Institute (RENCI) of North Carolina
- Sacramento Area Flood Control Administration (SAFCA)
- Scripps Institute of Oceanography
- Sea Grant
- US Army Corps of Engineers
- U.S. Bureau of Reclamation
- US Geological Survey

A number of collaborations have arisen amongst various academic institutions as well.

EFREP – An HMT Legacy

At the state level, HMT has joined with the California Department of Water Resources (DWR) to conduct the Enhanced Flood Response and Emergency Preparedness (EFREP) effort, a partnership between the CA Department of Water Resources, NOAA and the Scripps Institute of Oceanography, helping to implement several key findings from the NOAA HMT-West project in California:

Observing Networks:

- GPSMet sensors to track moisture as it moves inland off of the Pacific Ocean – the fuel for extreme precipitation
- Snow level radars to monitor the elevation of the rain-snow line
- Soil moisture sensors to track antecedent conditions for flooding and monitor surface conditions during droughts

Modeling:

- High-resolution ensemble (probabilistic) forecasts of precipitation
- Coupled to hydrologic models

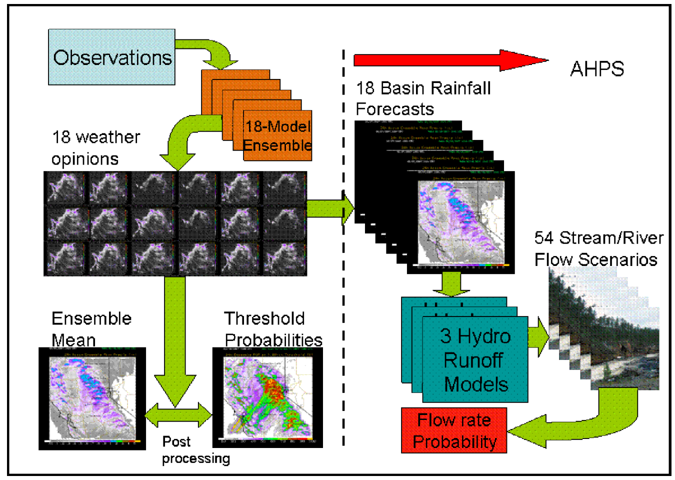


Figure 2.3 HMT EFREP ensemble-based system workflow.

These are key elements from tier-one of a four-tiered proposal. This is the vision for the ensemble-based hydromet decision support system described by Schneider, et al. (2008) for the EFREP (Figure 2.3). The Project Manager for EFREP, is Dr. Allen White.

The five-year EFREP plan builds on the HMT Program and is enabling part of the HMT-West Legacy.

CalWater

Another developing partnership with the California Energy Commission and Scripps Institute of Oceanography, called CalWater, is seeking to understand key elements of the impacts of climate change on weather and water. CalWater builds on the HMT-West framework examining the fundamental roles that (1) atmospheric aerosols (chemistry) and (2) atmospheric rivers (physical processes) play in changing patterns and intensity of precipitation in California.

2.2.5 Linkages to Demonstration Performance Measures

As discussed in section 1.1, performance measures help NOAA testbeds link science and technology advances to service improvements. By virtue of the Government Performance Requirements Act (GPRA), NOAA is required to report to Congress annually on a specified set of corporate performance measures. By their very nature, these measures tend to be conservative in nature and limited in scope, and are thus inadequate metrics for research programs. Nevertheless they remain important corporate metrics, and must be considered. Testbeds provide a framework within which formal GPRA measures can coexist with new or refined demonstration measures; NOAA testbeds are designed to address requirements of the GPRA in a pyramid manner founded on "Science" and "Technology" performance measures, building to "Infusion" and "Demo" measures, and ultimately supporting formal NOAA GPRA performance measures (Figure 2.4a). HMT provides a framework to accelerate improvements in existing NOAA Corporate GPRA measures and to develop new GPRA measures. For example, consider Figure 2.4b which is stated here in terms specific to the science and technologies for QPF. The work described under each of the seven major activity areas in section 4, is building towards specific performance measures for the various HMT demonstration activities.

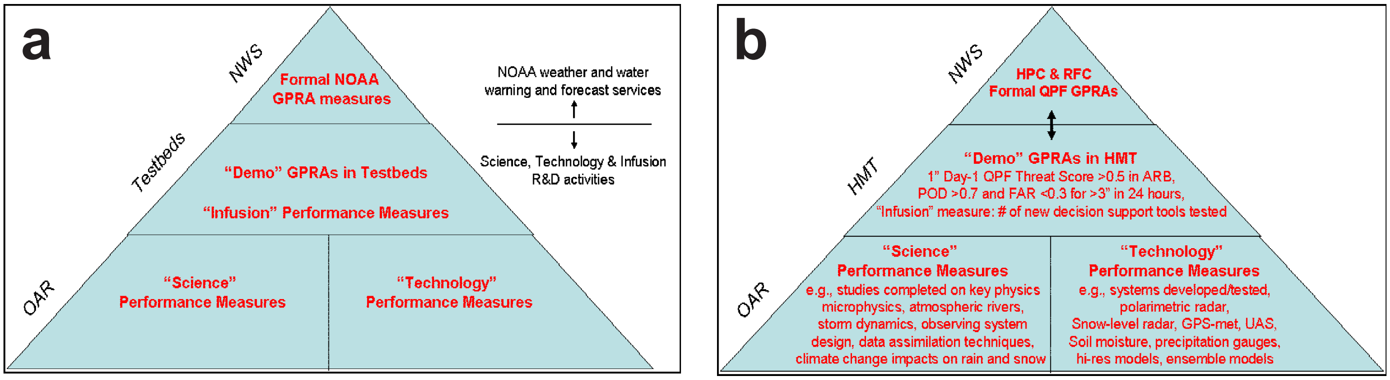


Figure 2.4 (a) Performance measures help NOAA testbeds link science and technology advances to service improvements. (b) An example of research, demonstration and formal GPRA performance measures.

2.3 Research to Operations and Technology Infusion

Research to operations (R-to-O) is one of the more challenging aspects of HMT for a number of well-documented reasons, including the wide scope of tools and knowledge to be transitioned (ranging from a simple algorithm to a complex piece of equipment to be deployed in the field), cultural differences and/or differences in roles and responsibilities between the research and operations communities, and considerations of funding.

The intent of R-to-O and technology infusion is to transition experimentally mature hydrometeorology information tools, methods, and processes, including computer-related applications (e.g. web interfaces, visualization tools), from research mode into settings where they may be applied in an operational and sustained manner. At present, the role of HMT in R-to-O is to develop prototypical systems, iteratively improve them with feedback from the operational community, and in some cases stakeholders, and demonstrate them in an operational setting, while building the business and requirements drivers to justify the new tool or technique. Presently a set of terms of references (TOR) are being developed that will further clarify and define HMT's role in R-to-O, as well as how OAR and the NWS can better partner on HMT transition issues.

2.4 HMT Management

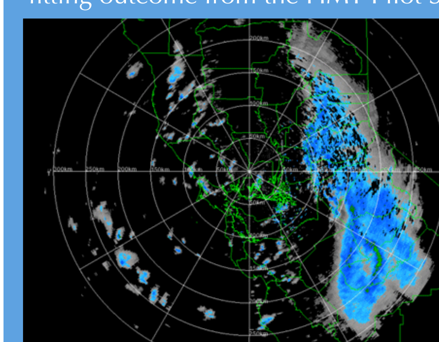
The HMT management structure combines a broad national view with focused regional views to address

NOAA Partnering with KPIX TV Station, San Francisco, CA

Posted: March 13, 2007

NOAA has partnered with KPIX-TV (CBS-5) to pave new ground. KPIX, the San Francisco area CBS television owned and operated station, has installed the first private weather radar in the region. This radar fills a critical gap in the NOAA NEXRAD coverage in this region. The "gap" exists because of the complex terrain in this area, which obstructs radar beams, the location of existing operational radars and the minimum scanning elevation allowed on the operational radars. The weather that affects this region comes in low off the Pacific Ocean, literally under the radar. Because of its location and its ability to scan at low elevation angles, the KPIX radar can "see" the incoming weather. This augments the region's NEXRAD network and gives the National Weather Service (NWS) forecasters in the Monterey office a big advantage.

An HMT pilot study helped to demonstrate the need for gap-filling radars in this region. These developments surrounding the KPIX radar constitute another first: this can be considered the first research to operations success story for a major observational facility from the HMT, a fitting outcome from the HMT Pilot Study.



The first 0-degree elevation reflectivity data from the KPIX radar on Feb. 22, 2007. The San Francisco Bay is in the center of the image.

the multidimensional nature of the water cycle. Executive oversight of HMT is provided by the HMT Management Council, whereas the HMT Project Manager provides day-to-day leadership on the program. Given the growth of the program, it was recognized that a new advisory structure was needed to support the management team (Figure 2.5). New developments include a smaller, but more broadly focused HMT Advisory Panel; Regional Implementation Teams, enabling regional focus areas to be developed and studied and facilitating R2O; the identification of an HMT Chief Scientist; and finally the creation of a new position, the HMT Field Operations Coordinator (FOC). As of this writing, the Advisory Panel is being reformulated, the FOC is being filled, and the HMT-West Regional team is largely formed (with a lead to be announced soon).

The following sections describe the membership and responsibilities of the proposed HMT management structure.

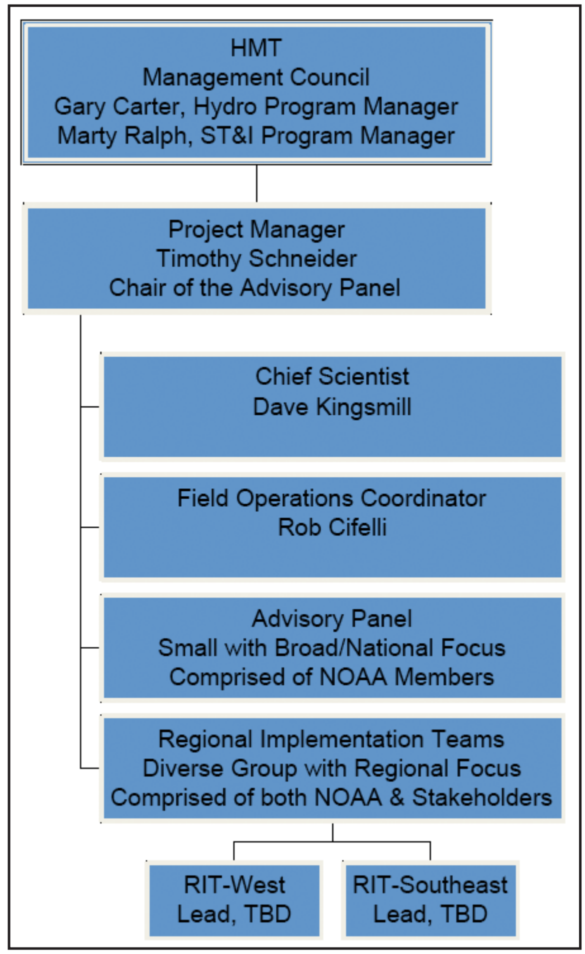


Figure 2.5 Organizational chart showing HMT management structure.

2.4.1 HMT Management Council (MC)

The HMT Management Council is composed of two NOAA Program Managers that provide overall guidance and funding for the HMT project:

NOAA Agency	Representative	Title
OHD	Gary Carter	IWF Program Mgr.
ESRL	Marty Ralph	ST&I Program Mgr.

2.4.2 HMT Project Manager (PM)

The HMT Project Manager is a NOAA employee responsible for day-to-day management of the HMT project:

NOAA Agency	Representative	Title
OAR/ESRL	Timothy Schneider	HMT Project Mgr.

Supporting the HMT Project Manager are the HMT Chief Scientist and the newly formed HMT Field Operations Coordinator. The Chief Scientist works closely with the Project Manager to provide scientific leadership to HMT and guides the experimental design of the HMT field operations. The HMT FOC works closely with the Chief Scientist and is primarily responsible for coordinating and executing the field studies, with support from the HMT field team. This recently identified position is in the process of being filled.

NOAA Agency	Representative	Title
OAR/ESRL; CU/CIRES	Dave Kingsmill	HMT Chief Scientist
OAR/ESRL; CSU/CIRA	Rob Cifelli	HMT FOC

2.4.3 HMT National Advisory Panel (NAP)

The HMT National Advisory Panel (NAP) has a national perspective and provides guidance to the Project Manager and the Management Council. The HMT Project Manager is the Chair of the NAP and all members represent different offices within NOAA. Membership to the NAP is determined by recommendation by the HMT Project Manager to the HMT Advisory Council who either accepts or rejects the recommendation. Pending approval by the HMT Management Council, the following NOAA Agencies will likely be represented on the NAP, with individual representatives to be announced in the fall of calendar year 2009:

- HMT Project Manager (chair)
- RIT-West Lead (regional representation)
- RIT-SE Lead (regional representation)
- NWS/OHD (hydrology representation)
- NWS/NCEP-HPC (national operational representation)
- NWS/OCWWS (requirements)
- OAR/HQ (transition person)
- NWS/MDL, NWS/OST (transition person)
- NESDIS-STAR (satellites/global precip)

2.4.4 HMT Regional Implementation Teams (RIT)

The HMT Regional Implementation Teams (RIT) focus on the needs and requirements of the different HMT regions (HMT-West, HMT-Southeast). In addition to providing regionally specific expertise and input to the experimental design of the testbed, and participating in and contributing to the conduct of the testbed, the RITs will also play a role in facilitating the transition of research to operations. Each RIT is independent of the other RITs. Membership is open to NOAA and non-NOAA Stakeholders and members can be on multiple RITs. Each RIT will have a Lead that works closely with, and reports activities to the HMT Project Manager. The appointment of the RIT Leads is made by recommendation by the HMT Project Manager to the HMT Advisory Council who either accepts or rejects the recommendation. Membership in the RITs is to be determined by the HMT Project Manager with consultation from the appropriate RIT Lead and the HMT Chief Scientist. As testbeds are established, new Regional Implementation Teams will be formed.

2.4.4.1 RIT-West

By definition, the RIT is a somewhat larger group and the composition is somewhat dynamic. Also some organizations have multiple members. At this time there are approximately 28 members on the Regional Implementation Team-West (RIT-West). The following NOAA and non-NOAA organizations are currently represented:

- OAR ESRL/PSD
- OAR ESRL/GSD
- OAR NSSL
- NWS Western Region HQ
- NWS CBRFC
- NWS CNRFC
- NWS Eureka WFO
- NWS Monterey WFO
- NWS Reno WFO
- NWS Sacramento WFO
- NWS OHD
- NWS NCEP/HPC
- NESDIS-STAR
- NOHRSC (NWS OCWWS)
- USACE
- CA-DWR
- Scripps Institute of Oceanography
- University of Washington
- Private Water Consultants

2.4.4.2 RIT-Southeast

Currently, HMT-Southeast is being considered as the next testbed. To date, two workshops have been held (February and June of 2009) to facilitate the planning process. The HMT Project Manager is leading this process with support from the HMT Southeast Ad Hoc Planning Committee. The Regional Implementation Team-Southeast (RIT-Southeast) will be established approximately one year ahead of the testbed initiation.

2.4.5 Integrated Water Resource Services-Priority Area Task Team (IWRS-PATT)

Priority Area Task Teams (PATTs) form a part of the NOAA's Regional Collaboration Effort. The PATTs exist on the national level to help develop a NOAA-wide strategy for addressing several priority areas. Current PATTs include one for Hazard Resilient Coastal Communities, one for Integrated Water Resource Services, and one for Integrated Ecosystems Assessment. The IWRS-PATT is directed to the long-range objective of "Summit to the Sea" life cycle water modeling. The HMT program is a key component of the IWRS-PATT in addressing state-of-the-art precipitation, soil moisture and snow- level estimations as inputs to distributed hydrologic models in complex terrain.

2.5 Operating Plan

2.5.1 Communication

Interactions within the HMT community take on a number of forms, depending upon whether or not field operations are occurring. The HMT web page (http://hmt.noaa.gov) is a primary source of information for both HMT participants as well as the public at large. News stories are added to the front page as frequently as possible to keep the pages current and to convey what is happening to the community. The web page also serves as a portal to much of the HMT data, and as an archive of key documents.

Off Season

Traditionally, annual meetings of the HMT Advisory Panel have been held in the spring. It is also common to conduct 1–2 "mini" HMT workshops; small groups focused on a narrow topic.

During Field Operations

During field operations (in the west this is typically from the

HMT Research to Operations (R20) Workshop

Posted May 14, 2008

The NOAA Hydrometeorological Test Bed (HMT) program sponsored a HMT Research to Operations (R2O) Workshop, 20-21 May 2008 and the HMT Annual Meeting 22-23 May in Sacramento, CA at the Joint Operations Center (home to the California-Nevada River Forecast Center (CNRFC) and the Sacramento Weather Forecast Office (WFO) and other federal/state agencies). Participants included researchers from NOAA;s Earth System Research Laboratory, National Severe Storms Laboratory, and the National Weather Service. Attendees will identify "technologies" developed in HMT, which are ready to be transitioned into operations in the near term, and develop an execution plan. Intended outcomes include an exchange of knowledge leading to a better understanding of NWS operational procedures, pressures and gaps at the CNRFC and in the WFOs, and a clear sense of HMT's scientific and technological developments to date.

A report will be developed that identifies one or more candidate technologies for infusion into NWS operations, long-term prospects, and an implementation strategy to achieve it.
HMT is a NOAA demonstration program designed to improve flood forecasting by accelerating the infusion of new technologies, forecast models, and scientific results from the research community into daily operations of the National Weather Service, including Weather Forecast Offices, River Forecast Centers and the National Centers for Environmental Prediction.

NOAA's Weather and Water Mission includes goals for improving the predictability of floods to better protect the public from losses of life and property. HMT provides a laboratory for NWS hydrologists and meteorologists to work closely with researchers from OAR to develop and evaluate new methods of monitoring and predicting extreme precipitation, which can be transitioned to operations. Lessons learned during HMT in the American River Basin can be applied elsewhere, in particular to the West Coast of the U.S.

beginning of December into mid-March), operations directors and lead forecasters are identified and each serves on one or more two-week shifts. The operations director is responsible for deciding when to conduct intensive operations periods (IOPs; i.e., both when to begin an IOP and when to terminate it), how to utilize available resources (sondes; field personnel, etc), and to write an IOP summary in a timely fashion. The operations director works closely with the lead forecaster, as well as the professional NWS forecasters to keep abreast of developing weather.

A number of blogs are also maintained on the web page on a daily basis (or more frequently as needed) during the field season. The two most important and useful blogs are the daily status and the daily forecast. However the most important form of communication during the field season is a daily conference call. It is important to keep these calls as brief as possible. During periods of relatively calm weather, it is common for these calls to last approximately five minutes. When a storm is imminent, the calls are more involved, and run somewhat longer. Long-range weather discussions are held as well, approximately on a bi-weekly schedule. These typically last on the order of one-half hour. After important IOPs (i.e., a "significant" event), a longer debrief call may be scheduled.

2.5.2 HMT Program Overview

2.5.2.1 HMT-West

HMT-West activities started in FY05 with a focus in the American River Basin because of the potential flooding of the Sacramento Valley due to critical management of Folsom Dam. The level of effort and activities in HMT-West increased from FY06 through FY08 with more field observations, more analyses,

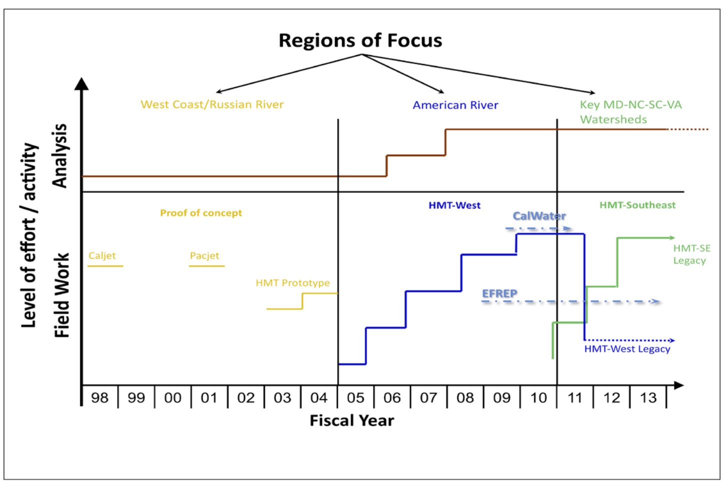


Figure 2.6 The HMT timeline spans over a decade and phases from one regional activity to another regional activity.

more modeling, and more communication between researchers and forecasters. As shown in Figure 2.6, the level of effort in HMT-West for FY09-FY11 will be comparable with FY08 and will decrease thereafter when there will be an HMT-West Legacy level of effort to maintain the lessons learned from the testbeds. Given current resources, HMT-West will need to reduce its level of effort in order for HMT-Southeast to begin and succeed. The regional hydrological problems that HMT-Southeast will address are still being defined and the requirements and scope of HMT-Southeast are being developed in FY09.

2.5.2.2 HMT-Southeast

The HMT-Southeast regional application project is being planned. Kickoff workshops were held in February and June 2009 in Chapel Hill, NC. The workshops involved the major stakeholders in a process of planning and project design; it will yield commitments for participation in more detailed planning and regional implementation activities.

2.5.3 Legacy Outcomes

The HMT testbed concept is founded on a regional deployment strategy. Given successful demonstration of advanced precipitation, snow level and soil moisture estimation techniques, selected components of the installed systems will likely remain as a legacy when the HMT experiments are completed.

2.5.3.1 EFREP

One example of an HMT legacy outcome is the Enhanced Flood Response and Emergency Preparedness (EFREP) project. The California Department of Water Resources (DWR) has signed a five-year agreement with NOAA's Earth System Research Laboratory (ESRL) to bring 21st century observation and modeling capabilities to bear on the state's water resource and flood protection issues. EFREP is joint project between DWR, NOAA, and the Scripps Institute for Oceanography. The underlying goal of the project is to improve precipitation forecasts, especially during extreme events. The planned statewide deployment builds on NOAA's Hydrometeorology Testbed (HMT) project carried out in the North Fork of the American River over the past three years. Recent research indicates that extreme precipitation in California is often associated with land-falling atmospheric rivers. Over the ocean the moisture content of these rivers can be tracked by weather satellites, however, over land ground-based instruments are needed. The planned deployment of instrumentation represents the first tier of a proposed multitier program. Taking full advantage of the new measurements will require a complementary effort in data assimilation, modeling and display. Decision support tools to integrate this new information into flood forecasts will also be developed.

2.5.4 Timeline and Milestones

The previous section defined the three regional efforts of HMT, limited resources (which include time and money) dictates that the regional efforts be implemented in stages with lessons learned from previous field campaigns used to improve future campaigns. Figure 2.6 shows a general timeline of HMT activities starting with the conceptual phase of isolated field campaigns focused on addressing specific scientific questions. The first HMT activities involved prototype field campaigns in FY03 and FY04. These activities focused on hydrometeorological processes on the West Coast and the Russian River Basin with efforts to improve communication between NOAA researchers and NOAA forecasters.

2.6 Training

The HMT effort takes long-standing, and/or newly developing science and technology, and places it in an operational setting to demonstrate and evaluate prototypes, and for proof of concept for weather and hydrology forecasts, warnings, and products. To this end, well-developed training, with inputs from the science and research communities as well as the operational communities, will provide a solid foundation for skilled operational use of the techniques, data, and decision-making in the operational warning and forecast process and products.

Training efforts will be focused on the proven and end-to-end usage of various tools, data, and techniques developed during the HMT focus area studies. The first of such areas, involving the west coast of the US, has already shown and proven the operational value of new data sets and modeling tools to operational forecasters. Those proven operational improvements are a substantial justification to invest in the widespread implementation and usage of HMT-developed resources/techniques in the operational settings such as the NWS.