

THE AGNES FLOODS

A Post-Audit of the Effectiveness of
The Storm and Flood Warning System of the
National Oceanic and Atmospheric Administration

Report for the Administrator of NOAA by the
NATIONAL ADVISORY COMMITTEE ON OCEANS AND ATMOSPHERE [NACOA]

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PREFACE

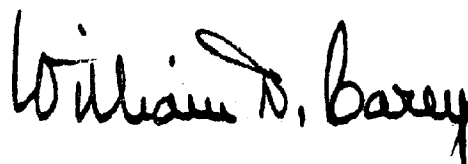
In any natural disaster of magnitude, the National Oceanic and Atmospheric Administration (NOAA), which includes the National Weather Service, mounts an immediate investigation to ascertain in what manner its grave responsibilities to the public were discharged and in what particulars improvements should be made or developments initiated.

Tropical Storm Agnes was a natural calamity of such extent that any system, designed primarily for day-to-day operations but with a readiness for ordinary emergencies, would have been strained to the utmost. Because of the magnitude of the disaster, and questions raised about the role of predictions and warning in such an exceptional event, Dr. Robert M. White, Administrator of NOAA, requested the National Advisory Committee on Oceans and Atmosphere (NACOA) to make an independent evaluation of the weather and flood forecasting-warning-dissemination system.

NACOA is a Presidentially-appointed oversight committee created by Public Law 92-125. It is charged with advising the President and the Congress on the Nation's marine and atmospheric activities, and the Secretary of Commerce with respect to the carrying out of the purposes of NOAA.

NACOA responds with this Report, the work of a special Panel. Though the NACOA Panel drew heavily on NOAA for the factual information on warning procedures and took into account NOAA's own Disaster Survey Team Report, the Panel has relied essentially on its own experience and judgment in its evaluation of NOAA's performance and in arriving at conclusions and recommendations.

We are aware of the high public praise by the Governor of Pennsylvania and by the Director of Maryland's Department of Public Safety and Correctional Services on the performance of the Weather Service. We are also aware of individual complaints about the lack of warning. We neither accepted blanket praise, nor investigated individual complaints except as they bespoke a general system deficiency. With limited resources we gave priority to critical aspects of the warning system we felt were susceptible of improvement.

A handwritten signature in dark ink, reading "William D. Barry". The signature is written in a cursive style with a large, prominent "W" and "B".

Chairman

NACOA Agnes Panel

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PART I: SUMMARY

OVERVIEW

Hurricane Agnes, which battered the eastern seaboard of the United States for four days in June, 1972 was an unruly storm which put to severe test the capabilities and skills of the Nation's weather and flood warning system. When it was finally over, a new record of damage stood: \$3.5 billion in property destruction. There were 118 deaths. Could these losses have been avoided or diminished through a more efficient performance of the warning services?

The answer is mixed. The system creaked but the people did well and some were outstanding. NACOA's judgment is that the performance of the National Oceanic and Atmospheric Administration, including its National Weather Service, was good. Taxed to the limits of its capacity, the system appears to have barely coped with the behavior of a most exceptional storm. What pulled it through were the people. But we do worry about next time. The national warning system is not geared -- and could not be -- to exceptional storms, like Agnes. The probability of repeat performances at frequent intervals is very low, and the Panel therefore takes the position that the costs to establish a fail-safe warning system scaled to disasters of an exceptional intensity would be unacceptable. A residual risk has to be accepted. But what this argues strongly for is a large and determined effort to bring the reliability of the system that we do have up to the highest standards.

If NOAA's performance had been letter-perfect, there would still have been prodigious property damage from a storm of Agnes' severity and intensity, and the loss of life may very well not have been less. But the issuance of accurate and timely warnings is only the beginning. There must also be a reliable system for delivery, a civil preparedness organization to cope with emergencies, and public understanding and response commensurate with the threat. We have built a sophisticated weather intelligence system but our understanding of how to induce appropriate public response is so rudimentary it can hardly be said to exist. Finally, the Nation's programs to reduce the public's exposure to danger are haphazard and in some cases contradictory. We are fortunate that we have not paid an even higher price in lives lost and property destroyed.

This suggests the priorities to be followed in strengthening our defenses against future weather disasters. While the technical and administrative resources of NOAA could be improved in certain respects and work must be done in the area of public response, primary effort must be focused on the warning delivery system.

Over the long run, preventive and protective measures for reducing vulnerability to such a catastrophe may be the most effective of all.

Responsibility for mounting this effort lies with NOAA only in part and in fact is quite diffuse. The Office of Emergency Planning, the Defense Civil Preparedness Agency, the Corps of Engineers, the Department of Housing and Urban Development, and state and local governments all have a role to play, as do the

media, schools, and the public itself.

Where system shortcomings were revealed by our review, and where means for overcoming these weaknesses have been suggested, the Panel finds itself in many instances anticipated by the implication of NOAA's self-examination and self-analysis.*

Where we think we may be of some help, is to focus attention on those aspects of NOAA's forecast and warning system which should be got at first. We have learned of programs, and groups of programs, which appear ultimately able to meet many of these needs. However it is not easy to tell what rate of progress to expect of them, nor whether the levels of effort are determined by criteria sufficiently related to the best strategy for system upgrading. We think it is essential to get at the questions of first things first because raising selectively the effectiveness of certain critical aspects of the forecasting and warning system can clearly have a more important effect, for a given effort, than raising the general level of the entire system a mite.

This is what our report attempts to do. It focuses attention on those critical aspects of the forecasting and warning system which we believe deserve first attention. To do this we followed a course, which is reflected directly in Part II (Discussion) of:

- assessing the "state of the art" -- could NOAA have squeezed more, during Agnes, out of what is now operational?

*"Final Report of the Disaster Survey Team on the Events of Agnes"
U.S. Department of Commerce, National Oceanic and Atmospheric
Administration, October 1972.

- assessing where current technology could be of greater help than it now is -- what is on the shelf which would permit rapid improvement?
- assessing the role observational feedback and short-term validation could play in improving forecasting -- how can communications and processing help make more data into better information and verify earlier judgments?
- assessing the role of dissemination to the public -- how critical is the absence of a responsible agency, the lack of systematic monitoring of public compliance with recommended action, the inconsistent attitude towards the role of long-term planning to reduce hazard?

MANAGEMENT EMPHASIS

There are several fundamental management issues with broad policy and procedural implications which underlie our recommendations. We wish to call these to NOAA's attention and to recommend that in dealing with the specifics, NOAA examine their relation to these areas of general importance.

1) Unusual Events and Decentralized Responsibility. There is a need for better central management of system performance for major storms comparable to that for hurricanes or tornadoes. For most situations regional and local networks can and do manage well. But if a storm is big enough, or odd enough, valuable time can be lost

while those with constricted jurisdictions are frantically adjusting to the exceptional needs of a larger event.*

2) Flash Floods and Normal Hydrological Procedures. For flash flood warning, NOAA has decentralized responsibility over normal hydrological procedures to gain time. But, whether for procedural reasons or by analogy, flash floods are treated as forecast problems rather than as triggers for pre-arranged action. The absence of practical lead-time, their highly localized occurrence, and the irrelevance of precise estimates of the flood stage, make the problem of flash floods as operationally different from river floods as the difference between defending against a bombing attack and a change of seasons. It seems clear that if you can't predict, you must provide guidelines to help others make sensible on-the-spot judgments.

3) Dissemination to the Public. There is a large grey area here in the handover of the warning from the National Weather Service to the action agencies. No single agency is responsible for finding out what makes a good warning or how it should vary from community to community and from individual to individual. A warning is often like the arrow shot into the air. The Panel feels that someone should find out where it falls.

*The Regions and local offices deserve kudos for what they did in Agnes. The point is, their job could have been made easier. Agnes may have "degraded" from an hurricane to a tropical storm, but which caused the biggest problem?

4) Flood-Plain Development. This may seem peripheral to the forecasting and warning system but the fact is that time gained in warning can be time lost by poor practices in flood-plain development. Potential damage avoided by forecast can be potential damage increased by accepting larger (if less frequent) risks. This is an important part of the picture and is one of the system elements which has to be taken into account.

These four broad management issues are the background against which the specific comments and conclusions below must be reviewed. To emphasize the Panel's strong views as to priorities, let it be said at the outset that it unanimously places the need for corrections in the delivery system for warnings at the top of the list. Close behind is the necessity to improve public response to warnings and to take advantage of available technology to make some specific technical improvements already within the state of the art. The premise is that unless warnings are comprehended and acted upon, greater sophistication of the weather intelligence system is not likely to pay off. But warnings must also be timely, and here there are tractable areas in which technological improvement would have important impact on total system performance.

FINDING AND RECOMMENDATIONS

The Panel finds that: The overall performance of the nation's weather and flood warning system during tropical storm Agnes can be rated as good. Though effectiveness was not uniform in all affected parts of the country, human performance must be credited with preventing critical system strains from turning into disaster. The benefit of hindsight points to some flaws and gaps in system capabilities of NOAA's storm prediction and flood data-gathering and warning system, to more serious deficiencies in the National capabilities for disseminating warnings and for anticipating public response to warnings, and to the inevitability of increased damages with inadequately regulated use of the flood plain.

In retrospect, those features of AGNES that contributed most to the disaster were: its erratic movement over Pennsylvania on the 22nd and 23rd of June, the virtually unprecedented intensity, duration, and spatial variability of its rainfall, and the over-topping of works which had been designed to withstand smaller floods.

The consequent hazards, for which timely and effective warnings were needed, were flash floods along minor streams and valleys and main-stem river floods along the major rivers. The hoped-for response to these warnings was strongly location- and time-dependent, varying from avoidance of threatened routes and areas to total evacuation of a metropolitan area.

The basis for our judgment concerning the performance of the disaster warning system cannot be in absolute terms. We have, instead, applied criteria that take into account the state-of-the-art of research, knowledge and professional practice, the extent to which full advantage was taken of available equipment and technology, the reasonable limitations implied by organizational practices, procedures, manpower levels, and qualifications, and finally, the limitations set by preexisting patterns of individual and property exposure.

Forecasting Performance

The Panel recommends that: research on the numerical forecast guidance model be pressed to increase the capability of forecasting mesoscale phenomena, with some emphasis on verification (by satellite, for example) as a means of correcting forecasts early enough to be of help; that the improvement in the forecasting and observation of the amounts

and locations of rainfall be pressed;
and that the special characteristics
of flash floods demand a fresh look at
the whole system with attention to
automated alarm and secondary methods
of observation.

The storm forecasting performance for Agnes was within the reasonable range of the state of the art, but considering that storm movement, development, and intensity were not caught on the evening of June 22nd when a double center formed, it would be desirable to accelerate the research needed to improve the ability to predict those aspects which are "local" to the general model, but all too general to the people on the ground. Pay-off from such research and development is likely to be some years off, but there is also reason to believe that improvement in data usage and verification can make the current predictive model more useful on a more local scale.

Rainfall was the villain in the Agnes disaster. The scientific capability to forecast the location and quantity of precipitation are not yet very good, and promise for improvement seems limited. Existing methods tend to forecast conservatively. That is, whether the forecasts are computer-generated or man-made, they are not likely to predict extreme amounts of precipitation. Since locations where precipitation will occur cannot be pinpointed consistently closer

than about a hundred miles when making a 24-hour forecast, all kinds of error can result (and, incidentally, can generate a credibility gap in the public's mind). Forecasters do not like to be caught with such mistakes, and tend to wait until the weather situation permits reasonable accuracy -- which means losing lead-time. In short, the basis for precipitation forecasting leaves a great deal to be desired. This again is an area where research and development should be pushed with long-term improvements in mind. In the meantime, knowing what is happening can take some of the sting out of limited forecasting ability. Radar is one of the most promising tools for observing rain falling. It has an important role in the transition of meteorological to hydrological forecasts and we shall come back to it below in the section on "Technological Opportunities".

Flash floods, by definition, are floods which occur with short, almost non-existent, warning times and are usually located along creeks, small streams, and constricted courses of flow. Main-stem floods, on the other hand, can usually be forecast with 6 to 24 hours notice depending as they do on information of what went on up-stream. In the case of Agnes in Pennsylvania and New York, river forecasting seems to have been beset by numerous afflictions. In some areas flash floods pounded in on top of main-stem floods (or vice versa). In others, deluges washed out gages and interrupted communications. Radar coverage was inadequate or not used consistently. Forecasts of precipitation amounts were

faulty. Communication systems were saturated.

The circumstances which conspired to create the problem were the unexpected and prodigious amount of rainfall, a data-collection and transmittal system vulnerable to the very rain and flood it was established to observe, and a processing-forecasting system designed for a pace to meet the onset of a river flood, not the onslaught of a flash flood. In addition the limits of human endurance, taxed as they tend to be in emergencies, were burdened with regular chores at the risk of clouding critical judgments and inviting mistakes.

The special requirements of flash floods, recognized in part by special hydrologic procedures, seem not to be treated distinctly enough, and tight manpower ceilings in field stations remove managerial flexibility in the special treatment for exceptional events.

Watches and Warnings

The Panel recommends that: NOAA examine its procedures underlying flash flood warning to make them more responsive to the requirements for triggering action, and that NOAA cooperate with appropriate government agencies to work out methods so that ambiguities on who is being warned can be reduced.

The floods triggered by Agnes brought on a profuse outpouring of warnings and alerts. Yet the evidence is that many people did not receive the warnings directly, misunderstood them, or did not know what to do with them. In some cases the predictions of flood stages during rise were off the mark or late, partly as the result of crippled observation and communications systems. There was no quantitative lack of warning. But the quality of the warnings was not uniformly good especially when disaggregated to local situations.

We spoke above of the difficulty in estimating rainfall. Here we speak of difficulties in judging what flooding the rainfall might produce. Warning is the end product in a long chain of observations, correlations, interpretations, analyses, and estimates. To get at how one can improve warning quality we consider three aspects of the situation - information, judgment, and warning.

A warning can be no better than the information input whose quality is a combination of accuracy and the reliability of the observational and reporting network. The best technology and the most sophisticated models won't work when a power system fails or an observer can't reach a telephone to report a gage reading or can't reach the gage. In the case of Agnes the fact is that, in the data-collection phase, the special needs of flash flood warning stand out. While NWS uses its own observers (many voluntary) it mostly uses everybody else's river gages. This might work fine with ordinary floods, but is unsatisfactory in more critical situations.

Secondly, there is the question of how to process the information that comes in so as to make a good judgment on what it means. River stage forecasting can be very precise, but to be precise it has to take into account past experience, current soil and river conditions, and what rain is falling and where. This is food for computers and that is precisely what happens. The information collected by River District Offices is forwarded to the River Forecasting Center where riverstage computations are made and the forecasts are forwarded back for local distribution. In a crisis, short-cuts are mandatory. They are, the Panel understands, being experimented with. Guidance is offered to some public officials on what riverstage would be reached on a particular day if a certain amount of rainfall occurred. The man on the scene can spot the possibilities as events develop. We encourage development of this practice which is in use in particular Weather Service installations. This "what if" arrangement has all the features of an emergency plan, ready for use when an emergency arises.

Lastly there is the public confusion between readiness (the watch) and the call to action (the warning), and for whom either is intended. A very real problem is that flash flood watches and warnings are fairly new. They are general in their wording (such as by counties) and unless the listening audience has suffered in the past and knows a flash flood for what it is, the warnings may not have much effect. The compulsive mobility of people to move

from cities and suburbs to areas where flood risk exists, and their innocence of the risk, poses major problems of disaster readiness which the warning system by itself cannot handle. So far as the NACOA Panel knows, there are no provisions in state or county ordinances requiring public posting of flash flood danger in vulnerable communities. Nor do safeguards exist in Federal homes financing programs to alert homeowners involved in purchase and transfer of properties in flash flood areas. Public inertia in this regard deserves a share of the blame for the consequences of Agnes.

The Warning Delivery System

The Panel believes that: delivery of emergency warning, as if one were sowing seed, leaves too much to chance and that it is NOAA's responsibility to make certain that appropriate agencies -- agencies who can take action -- get the message and understand the warning intent. This may mean automating certain features (flash flood, for example). It certainly means making certain of two-way dialogue and soliciting the help of the Office of Emergency Planning in coordinating and encouraging the efforts of recipients to improve the effectiveness with which they can use warnings such as:

- Extending the flood vulnerability analyses by the Corps of Engineers;

- Reinforcing the present delivery system by greater use of public networks via grants from the Law Enforcement Assistance Administration;
- Testing various kinds of automatic alarms and warning;
- Working with the media on procedures for handling and interpreting flood and flash flood warnings;
- Providing the NOAA Weather Wire to drops in all communities of 25,000 or more at government expense.

The arrangements for transmitting warnings to the public are fragile and makeshift. The National Weather Service has almost no role in reaching the public directly, other than by answering the phone. NWS of necessity relies upon the mass news media including television and radio. NOAA provides a Weather Wire Service via direct teletypewriter circuit from weather offices to subscribing news media and other interest groups. Not all news media buy the Weather Wire. The media get their information on weather conditions mainly from the press wire services. There are delays in the relay process. Overall, less than 10 percent of the news media in the stricken areas had continuous access to the latest forecasts and warnings. To make matters worse, it appears that some subscribing stations actually overlooked the forecasts and bulletins though the press wire services gave "bulletin" status to most of the

warnings. Once the media understand that it is an emergency, they do a great deal, but otherwise they don't move fast.

NWS tries to get its message across in other ways. It uses automatic telephone answering devices, direct broadcasts on commercial radio stations, manually answered telephones, continuous VHF-FM radio broadcasts (although the range is very limited), and indirect channels such as state and community action agencies. Telephone and radio are the only real means that NWS has to warn the public directly and their one-way nature is such that the public cannot, in general, get back to the Service if something needs clearing up. If you don't have the right number, a taped answer to a question you didn't ask may be all you can get.

The fact seems unarguable that accountability for warning delivery is fragmented to the point where no agency has the responsibility. When you add to that technical difficulties in pinning down flash flood probabilities to particular areas, the understandable tendency is to hedge as to the local regions involved. This clearly affects believability and response. Some of this could be mitigated by a system of "internal" alerts where "internal" includes action agencies such as civil defense and the police. It is, in any event, essential to try to find out, on the local level, how you should warn effectively in that particular place. You can do this only if a two-way dialogue takes place and some thoughtful investigation is done before emergencies arise.

NOAA now makes certain their warning messages are sent. NOAA should undertake the responsibility of making certain that the warning messages are delivered to someone who can take action.

Public Response

The Panel recommends that: a monitoring component to permit feedback can and should be developed by the NWS to sense in conjunction with the appropriate action agencies, information on public response. It also recommends that the language and terminology of the warnings must be changed if people are to get the message. No warning is likely to be efficacious when communities have no emergency action plans or mobilization agencies. Federal incentives and technical assistance should be provided to create such plans and organizations where they are absent, bearing in mind that a system designed for effective response must be designed in a broad sense which avoids specialization by disaster.

Who is responsible for monitoring public response to emergency weather warnings? Apparently, it is not a Federal responsibility. Presumably, then, it is a state or community responsibility. But consider the contrasts. We have a massive system for gathering

weather intelligence and issuing warnings. We have no system at all for monitoring on a real time basis the quality of public understanding and response. The feedback comes too late. Considering how much we know about opinion survey and market research methods, NACOA believes that a monitoring component can be built into the NWS to sense public understanding and response to warnings with live feedback. The quality of public response during Agnes was mixed. When public authorities exercised strong command and control initiative, the response tended to be excellent. Where people had to make their own decisions, or had to improvise, the response was as varied as human nature. When radio or TV announcers conveyed a sense of the seriousness of the risks, the public became more responsive. Past experiences counted for a good deal. So did the wording of the releases and the length of lead time. Age apparently had something to do with response: older people in areas which experience occasional minor flooding were inclined to stick it out, while younger people in the same areas were more disposed to move. Many who did respond had only vague ideas as to what they should do.

There was confusion and misunderstanding. In some areas few people could tell the difference between watch and warning, between main-stem and flash floods, and the different lead times that went with each. Others felt a false sense of security about reported events 50 or 75 miles away. The watch-warning confusion led some to think that the NWS was "crying wolf" when in fact watches had been issued to

alert the public to possible warnings. Confusion between flash floods and river floods caused erratic response to river flood warnings issued after flash flood waters began to recede.

Even in Pennsylvania, where there is good civil defense well-prepared to cope with natural disasters, this organization faced the problem of lack of awareness on the part of people in threatened communities regarding their vulnerability to flash floods. There were people to whom the 1936 flood of record is legend, who are more accustomed to think in terms of main-stem flooding than flash flooding, who live in communities where dikes and levees provided a sense of security normally justified but in this case unwarranted, and who missed the late night and early morning warnings at the critical juncture. The inability of the local agencies and news media to equate forecast stages with potential flood damage areas also delayed public response.

The NWS has its hands full tracking the weather, forecasting things to come, and issuing warnings. It can hardly go into the streets as well. But what it must do is see to it that its warnings are understandable. Its credibility is sure to slip if it speaks to the public in codes or symbols. Time is too short to wait for translations. NACOA strongly recommends that NOAA review its battery of warnings to develop improved ways of communicating warning information, bearing in mind the needs during disasters other than flood. As an example, it could use a four-tiered system such as:

- (A) "Flash Flood Threat -- Condition Yellow -- No immediate local danger -- Stay close to your radio for bulletins."
- (B) "Flood Situation Bulletin -- River X is expected to reach a crest of blank feet in Y hours -- Flash flooding will occur on streams and tributaries blank hours before the main-stem reaches its crest -- Stand by for flash flood emergency warnings."
- (C) "Flash Flood Emergency -- Condition Red -- Repeat, Condition Red -- You may be in danger -- Follow civil defense instructions."
- (D) "Flash Flood Stand Down -- Conditions normal -- Thank you for your cooperation -- Did you know what to do this time? -- Remember, there may be a next time."

Even if the meanings of successive warnings are made clearer, no warning is worth much if no local action plan and an organization to carry it out exists. The Federal government cannot force communities to create these plans and organizations, but it can provide them with incentives to do so. Moreover, the Federal government can and should provide guidelines and technical assistance to communities of 25,000 or more. It can work with state governments in designing appropriate legislation for emergency preparedness and the posting of flood-prone districts. NACOA believes that priority should be given to improvements in the delivery and public response elements of NOAA's mission.

The Panel had to ask itself whether anybody is really responsible for monitoring public response to warnings. We decided that apparently nobody is, except after the fact. We have a massive system for gathering weather intelligence, but no real-time system for feedback regarding public understanding and response.

Technological Opportunities

The Panel recommends: that the possibilities be investigated of improving data validation, update, and assimilation procedures which would permit models to be used in more timely fashion during sensitive periods in weather formation.

that satellite observations in real-time and space be used as a check against the theoretical forecasts by the computer model which would permit much earlier correction of the model than is now possible.

that the limitations of radar observation of rainfall amounts because of isolated operator interpretation (however assisted) be removed by digitalizing the returns and processing than at a central facility. What we propose is simpler than D-RADEX which computes at the site and may be over-sophisticated for general use. The digitalized signal can be sent by

telephone line without loss of information because it can be processed at modest cost for narrow band width communication at the site.

that the separate requirements for flash floods and main-stem floods be reflected in separate - if need be - river gage systems and that plans for flash flood preparedness, distinct from river flood forecasting, be pursued.

that the communication and information-flow technology at the local, disseminating level, during operations in routine and in emergency situations, be examined with a view to modernization and stream-lining.

While no system for day-to-day routine operations is instantly transformable into an 100% efficient emergency operation, Agnes exposed enough flaws in forecasting and precipitation-estimate ability to make it worth considering investment in enhanced technological capability where it would produce more than marginal gain.

It is not a question of whether Agnes is likely to hit the Eastern U.S. again next year, but the fact that there are big and little Agnes's all the time. Enhancing the overall national ability to improve weather warning in emergencies has a national payoff not measured by individual one-hundred year storms.

The Panel asked itself whether the experience with Agnes pointed to means by which current technology, for which development costs have been largely paid, could improve forecasting capabilities under emergency conditions, and lessen the communications problems and breakdowns in collecting, processing, and disseminating weather information.

We believe that the recent dramatic increase in capability, and dramatic decrease in cost, of data processing and storage devices permits just that. Most of our technical suggestions for improvements in forecasting (both meteorological and hydrological), warning, and dissemination, based as they are on data handling and communications, depend on the recent breakthrough in information-processing technology.

The primitive equation model and the limited area fine mesh model, both products of the NMC, rely on the basic global weather network and (the LMF) on the North American radiosonde stations. The trouble encountered in Agnes, however, was that features of air-flow producing the unprecedented rainfall in smallish areas (meso-scale) were too fine for effective resolution by the grand models. We have reason to think that even with existing data, but using

verification techniques and greater caution in rejecting anomolous data, improvement is possible in numerical guidance on mesoscale development. Another reason for difficulty with the numerical guidance model is that radiosonde observations are now taken at intervals of 12 hours which is too long an interval for mesoscale phenomena. The question we ask is whether, by developing an ability to call for more data one could get the finer grain data when needed without the prohibitive expense of making such extra observations routine.

PART II: DISCUSSION

STATE OF THE ART

Could the Weather Service, given what is now operational, have done a better job in meteorological and in precipitation forecasting? The two elements of weather forecasting are, of course, interrelated but will be considered separately here. They are:

- The deepening and movement of pressure centers; and
- Precipitation amounts and location.

Pressure Center Movement

In the past decade there has been a distinct improvement in the National Meteorological Center's (NMC) ability to predict the twenty-four hour movement of storm centers and some improvement (but far from adequate too frequently) in their ability to forecast deepening or filling of pressure centers, and the formation of new pressure centers. The average error in twenty-four hour predictions of hurricane centers is about 106 nautical miles and for twelve-hour periods about 50 miles, and these are of the right order of magnitude for slow-moving extratropical storms as well. Unfortunately, the really big errors either in direction, speed, or changes of central pressure are usually made in cases where the storm performance is most unusual and this creates sometimes massive errors in the resulting weather forecasts.

The storm performance forecasting for Agnes was within the reasonable possibilities of the present state of the art. The forecasting of storm movement was quite good until the evening of the 22nd, although the central pressure of the storm was badly over-estimated from the morning of the 23rd (that is, the storm was much deeper than forecast). On the evening of the 22nd a double center formed; one in southeastern New York, the other in Northeastern Pennsylvania. The double center was likely part of the process of the storm changing from purely tropical to extra-tropical and incorporating the cold air in Western Pennsylvania in its circulation. This probably should be considered as a new storm rather than as Agnes and its movement was entirely foreign to the part of the movement of the now defunct Agnes. The cyclogenesis and subsequent movement of the center west and south was poorly forecast. It is true that hand-prepared hourly weather maps would have picked up the formation of the new storm center mid-evening of the 22nd, but it is far from certain that this would have produced a better future track forecast and consequently improved the precipitation forecasts.

We are dealing here with present inadequacies in the state of weather forecasting and if future storms of this one's unusual nature are to be forecast better, it will be necessary to improve forecasting technique and ability. As we have noted, some progress has been made along this line but it has been slow, and more research effort is required. For example, it is our understanding that some recent developments at the National Center for Atmospheric Research (NCAR) using computerized parameters involving isentropic surfaces have, in a few tests, produced superior

prognostic surface charts. We recommend that this, as well as all other promising avenues of research, be explored, for this is the very essence of the problem which must be solved if all kinds of weather forecasts are to be improved. We also recommend that arrangements for comparing numerical model forecasts with satellite observation for weather systems, as is discussed in more detail in the next chapter, be considered although we realize it may be initially complicated to effect.

Precipitation Forecast

Numerical objective forecasts involving the locations and amounts of precipitation 12-24 hours ahead are fairly new and the state of the art is at best crude. The present methods are biased towards conservative forecasts--that is, neither the computer-generated forecasts nor the subjective man-made ones like to forecast extreme amounts of precipitation. Furthermore, the problem of locating the area over which precipitation of specified intensity and duration will fall is most difficult, and can certainly not be placed consistently closer than about a hundred miles.* Consider the problem of two adjacent watersheds separated by a range of mountains. An error in locating the precipitation area of even sixty or seventy miles could easily cause flooding in the unforecast watershed and no flooding where it was forecast, thus producing a double error. It is not strange that the men who have these forecasts to issue are most reluctant to be bold and forthright in their forecasts but rather to approach them gingerly, gradually targeting their objective only as the weather situation develops enough to allow them to avoid making a palpable error. This is the present state of the art.

* In 12-to 24-hour forecasts

As far as Agnes is concerned, it may have been either a convergence line or a true "squall line" which was associated with the heaviest rain of the storm. It does not matter whether the convergence was the cause of the heavy rain or the result of it, but it is significant that the phenomenon was apparently restricted to levels below 850 mb (5,000 ft.). With such a subtle action and restricted volume of air being all that could be tied to the heavier rains, it is apparent that here we have a good illustration of the almost micro-nature of such storms and of the extreme difficulty forecasters face in attempting quantitative precipitation forecasts or even to observe variations at this scale. This, by no means, is intended to indicate that solution of the problem is hopeless--rather there appears to be plenty of room to devise improvement. Our knowledge of the area is now only a start. If significant improvements in our ability to forecast cyclogenesis, deepening, filling and future tracks of cyclones can be obtained, then an immediate improvement in precipitation forecasts will also ensue.

Precipitation Amounts

The performance of NWS in predicting the amount of precipitation in Agnes was less than good. For example, at Harrisburg, the total amount of rain forecast for the storm was less than six inches, while over fifteen inches fell. In other areas the record was better. Nevertheless, in the light of the difficulties involved in making these forecasts, we do conclude that they were within the present "State of the Art" although perhaps crowding the edge a bit.

Radar For Reporting Precipitation Amounts

Despite that fact that weather radars have been used since World War II, their use for measuring quantitative precipitation and rates is still in an early stage of development. The NWS, as it should, has been in the forefront of this development, but it has proceeded rather slowly due to the immensity of the task, budget limitations, and constraints of the technical aspects of the problem. We will discuss here what current use is made of radar reports and its limitations. In the next chapter we will treat improvements we believe possible using current technology.

Coverage

For the purpose of rainfall rate measurement, the nominal 250 nm range of the basic NWS radar, the WSR 57, cannot be used because the radar beam is too high above the surface of the earth beyond a hundred miles or so and also because attenuation of the beam greatly decreases its reliability beyond this range. Accordingly, their use for this purpose is limited to the 125 nm range. Figure 1 shows the location of the primary radars in the concerned areas and the circles indicate each one's coverage assuming a 125 nm range. Even the outer 25 or 50 miles on this range is reduced somewhat in accuracy because at 125 miles the radar beam elevation of about 14,000 feet due to curvature of the earth may be above much of the heavier precipitation. Attenuation of the radar beam from various causes may result in underestimation of rainfall rates. Thus, although Figure 1 might lead one to conclude that the Pennsylvania area is fairly well covered, the center of the state is not. It is possible that most hydrologists and weather forecasters

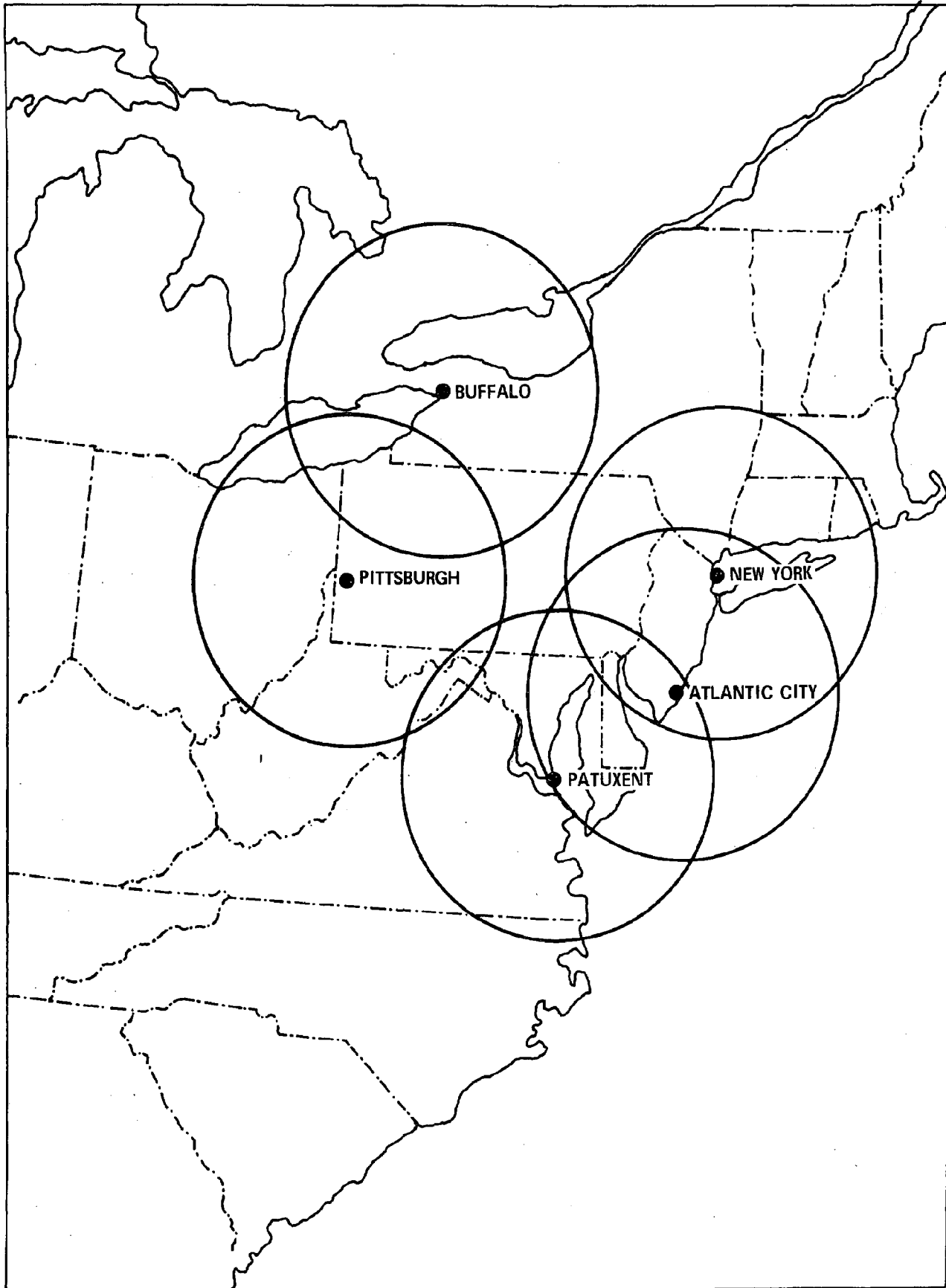


Fig. 1 - Locations of primary radars and 125 NM circles of effective coverage.

would either fail to take these things into account under the extreme pressures of flood conditions unless called to their attention by radar observers or specialists, or on the other hand they might just disregard them. Although Pittsburgh and Buffalo have a new device called Video Integrator and Processor (VIP) which helps the operator assess the returns and thus different rainfall rates, they are not yet completely calibrated and it is likely that considerable underestimation of rainfall rates resulted. Of these radar stations all reported that "moderate" was the highest intensity of rainfall observed during Agnes, except New York which reported "heavy." It should be noted that moderate is defined as from 0.1 inches per hour to just under 1 in/hr. Rainfall rates within this range--continued for several hours--could clearly be given to revising the definition to cover accumulation of rainfall. Nevertheless, whether for lack of aided interpretation or lack of calibration, radar coverage for the purpose of reporting precipitation amounts is scantier than would appear at a glance, and the information produced, for a number of technical and operational reasons, tends to be conservative and results in underestimation.

Use of Radar Reports

It is the practice of radar observers in NWS to report areal extent of precipitation in advective weather situations with rates of precipitation given in remarks, if at all, while the primary report is rate of rainfall in convective weather situations. It is unlikely that this practice curtailed any pertinent rate of rainfall information in the

case of Agnes because, although the storm was mostly advective in character, it did have convective cells and, furthermore, all concerned knew they were dealing with a flood situation and that rainfall rate was vital as well as was the area is covered.

In the next section, on flood forecasting, comments will be made on the timing of forecasts of flooding and flood crests with relation to rainfall, but here it is appropriate to attempt to capture the role played by the radar in this process.

One interesting means of ensuring that radar returns are used and interpreted properly by radar specialists, who frequently are remote from the RFC or RDO making the flood forecasts, has been developed by the Eastern Region of NWS for Atlantic City, New York, and Patuxent River, Md. It is called "Hydrology Procedures" and is designed to aid in flash flood forecasting. The plan includes a procedure for the RFC/RDO's to provide headwater statements that will indicate three-hour rainfalls required to produce flooding within 125 n.mi. of the radar. The radar specialist contacts the RFC/RDO duty forecaster whenever the amounts in the headwater statements are approached. He also prepares PPI scope special overlays indicating areas of heavy rain. This procedure was apparently not in effect over the entire region affected by Agnes and we are not in a position to judge whether it made a difference in these areas in which it was in effect as compared with these areas in which it was not. But it does not appear from later analysis, considering erratic superimposition of floods and flash floods, that

radar helped distinguish between the two.

Radar's primary use appears to have been to keep forecasters alert to the fact that the rainfall was continuing and that "moderate" rain was falling over areas where conditions had already become dangerous. Intensity rainfall rates are determined several different ways when using the WSR-57 radar, one of which (the VIP) calibrates the radar return intensity and locates it geographically, while the others (the LIN ATTENUATORS) aid in judging the intensity of the radar return. Eventually, we understand, all WSR-57 radars are to be equipped with the VIP, which is certainly the easiest and most accurate procedure of this type for the radar observer to use. But this leaves open the question of whether using the radar observer interpreter, even when VIP levels are standardized, is the best way to handle the information. We will return to this again.

Lastly, it appears to us that although the Eastern Region of NWS has shown awareness of the problems in improving the use of the radar reports for hydrological procedures, we sense there remains an area, between the radar sets and observers on one hand and the final flood forecasts on the other, where this tool is not being utilized to its maximum effectiveness.

WHAT CAN CURRENT TECHNOLOGY DO?

Introduction

Even if the weather system performed admirably in some cases and reasonably in most we must still respond to the essential question: could it do better if more advantage were taken of current technology?

Considering the magnitude of the disaster in terms of lives affected and damage suffered, the number of lives actually lost might have been much higher. A twist of fate, or less vigilance on the part of the hundreds of people whose performance seems to have matched the demands in an event of such magnitude, might have produced an almost unimaginable disaster. What if the evacuation at Wilkes-Barre had been delayed?

The panel is not satisfied that the susceptibility of lives and of property to a "twist of fate" cannot be lessened and that the precariousness of the outcome for a guardian system cannot be diminished by improving, even within the current state of the art, certain key elements of the forecast system. The purpose of this improvement would be to buy time in flood forecasting, flash flood forecasting especially.

Several facts about Agnes stand out:

- The turn westward of the tropical storm and its combination with a second weather system over Pennsylvania and New York was apparently missed by the newly operational LFM forecast model. Events overtook the forecasts.
- The intensity and quantity of rainfall which the combined weather systems produced was not, in general --at least in the North--predicted and not in all cases reported as the weather washed out observation points.
- The continued rainfall for days and its reintensification caused a combination of flooding and flash-flooding which

in some localities confused some users of NWS information--public and official.

- The intensity and suddenness of flash flooding in some areas was too great to be believed and too sudden to give its own warning.

Where could technology have helped?

Extreme Weather

We are concerning ourselves here with more effective performance in extreme or in surprising weather situations. This is a necessary distinction because, under normal conditions, the weather service provides an opportunity for public and private activities to adjust to weather in stride -- almost at leisure -- while, in highly unusual situations the weather service must gear up to save lives, lessen the possibility of injury, and provide as much time as possible to permit protection of property which, for whatever reason, is already at risk.

Our emphasis on extreme weather conditions is significant, for in such situations the demands on the forecasting process undergo a change which may be difficult for an organization to provide for when its activities are usually routine, even though the penalties for delay and for misinformation are greater. We find no evidence that the organization failed to perform in expected fashion during the initial stages of Agnes as information, predictions, and advisories poured out of the National Hurricane Center on schedule or accelerated as planned for in special events. As the storm moved up the coast,

the responsibility for storm-warning guidance on Agnes moved into the Regions and thence to the local offices. Given the good grace of decent communications, established procedures were followed for gathering information, collecting it, passing it to centers for computation, returning the computation, making the forecasts, and for determining what watches, warnings, alerts, or alarms should then be disseminated outside the weather system.

But there is an important deficiency in unusual weather situations. Instead of having more time to check things out with one's neighbors there is less, instead of more experience to fall back on there is less, instead of more assurance about prediction there may be less. When the need to be sure is great, the time to decide is short. What persists as a nagging question is whether time could have been saved during Agnes if there were some means for central management of major storms.

Another difficulty in handling exceptional events with an organization geared to full employment during routine activities, is the inability to interrogate the forecasting system with special demands such as verification, updating, etc. In routine operations, time and redundancy can overcome this isolation. In emergency situations they cannot. In normal situations, prognostications are checked against neighbors' and the comfortable consensus can be reached. In emergencies instead of having better information and more redundancy, the opposite can be true; information is more restricted, more extreme, harder to depend upon, and there is less time to hedge one's bets.

Feedback and Central Management

The need for feedback is the striking feature of every element of the system, technical as well as non-technical. At each stage, there is need to sense how the information being passed on is used, and to modify what is being passed on is used, and to modify what is being done (or supplied) in light of what is happening or what is understood. This need is as valid in technology, where real-time matching of model forecasts and actual weather could be used to correct model forecasts, as it is in dissemination where a sense of how well or how poorly a flood warning has been perceived can make all the difference between effectiveness and failure.

Feedback is dependent, of course, on proper communications and the proper and timely use of what is communicated. If the feedback path is slow the information is useless or, if used, can do more harm than good. Later on we will deal with external communications to media, to action organizations, and to the public, and with public response. Here in this chapter and the next we will deal with the timely internal communications involved in observation, collection, computation, verification, and dissemination of the weather forecasting (raw material and product) and in particular what junctures could stand improvement and where technology can help.

The need for improved feedback in internal communications thus expresses itself in two operationally distinct ways -- managerial to meet the unfolding of the storm with the best strategic use of the organization capability at hand, and technological to permit the best

tactical use of the data on hand so as to get the most out of it.

The first we will not discuss further because once the necessity of such central management is accepted, it is usually easier for insiders than it is for outsiders to come up with a plan. The second we wish to treat in some detail because we believe here that we can stir things up usefully.

Five Areas For Improvement

Within the last several years a revolution has taken place in both the power and the price of data handling and data processing elements which make what were academic dreams two years ago practical and feasible today.

Transistors were invented in 1948. They were first used in space-craft in 1958 at \$27.00 each. Now integrated-circuit technology (an entire circuit on a chip) has increased the reliability of complex circuits and reduced the costs dramatically. One can now carry a computer in his vest pocket at a cost of a good camera. It might contain tens of thousands of transistors at a cost of a penny each. During the last two years especially, developments in complementary circuit technology has reduced power requirements so greatly that it is possible to build an entire automatic weather station which can give wind speed and direction, pressure, temperature and moisture -- with a half dozen channels left over for future use -- and is light enough to be hung on a string! Other technological developments in communications indicate that the whole country is rapidly being made accessible to wide band communications.

NOAA will soon have its own data gathering geostationary satellite.

It is hard to stop a good idea once its time has come. What this means is that without pressing the state-of-the-art, and with reasonable cost, there are at least five junctures in the forecasting-warning process in which marked improvement can be made by applying available technology.

Except for being dedicated to the same general purpose of improving weather forecasting, and some similarity in technical requirements, the improvements are independent of each other. If any were accomplished, it would help, if all were accomplished, it would help most. If they were coupled with central management of the affected areas (as is now done in part by the regions) and at the other end with improved dissemination effectiveness at the local level, the ravages of floods susceptible to improvement in forecast and warning procedures could be lessened over what they are now. These areas which can be marked for improvement are to:

- Improve data update assimilation;
- Verify model forecasts by real-time match with satellite data;
- Use radar more effectively for rainfall measurements than is even currently proposed;
- Distinguish technically between river (main stream) floods and emergency (flash) floods;
- Improve dissemination of information both within the warning system proper and to the action agencies and the public.

Validating and Updating Models

In this section we consider how more flexible assimilation of observations could improve performance of the observing system by setting data in context, by validating critical observations, and by updating information at crucial times.

Observation technology enters the prediction process in several ways: observations are needed as initial conditions for all forecasts be they made by man or by machine; observations must be communicated to the user in an expeditious manner so they are available in time and at the right place so as to be of use; observations may be used to check the general sense of evaluations; and observations allow one to check the validity of earlier predictions. We will discuss the communications aspects of these requirements below. Here we suggest for consideration avenues of use to which current data might be put in models to improve current forecast performance.

Most instruments collect data only, when what is needed is information. If we are nearly drowning in data, we can lose the information within it. Good detail when disseminated without a sense of the context in which it fits, can confuse. Two kinds of information are therefore needed: detailed information, and information which helps one understand the big picture. If one has the big picture, detailed information sharpens one's understanding of what is going on at the moment and what is likely to happen in the future. The system must provide this kind of key information.

We raise this point because the limitation of the general numerical guidance models usefulness on the mesoscale might be widened by incorporating appropriate observation, on call, during exceptional events. Both NWC computer forecast aids which describe and project the general motion field (the primitive equation model and the limited area fine mesh model), rely on the basic global weather network. The LFM model uses the radiosonde information from North America in particular. On the other hand, the hurricane and the weather system responsible for the extremely heavy precipitation in the middle Atlantic States were mesoscale systems smaller, generally speaking, than the effective resolution of the models. Yet aircraft, radar, and the satellite provide important observations on this smaller scale. Is there a way of bringing in such "outside" information in special situations?

Numerical guidance on mesoscale development, we were told, is not feasible. We think this too modest a judgment. The general field of flow sets up conditions for the mesoscale. It may be that lack of data is not a problem, but how it is used may be. This is why we feel observations, dictated by context, will permit the model to be extended. Although a key report for Greensboro, North Carolina was missing on the 22nd, the serious errors in prediction occurred further north. On the other hand, on the 23rd, Greensboro did provide a key observation but the analysis algorithm (the filter which rejects data that would send the model out of control) probably rejected this vital observation.

This may be a key factor. The scheme for identifying observational errors, called initialization, is necessary to protect the model from logical inconsistencies in the data for which it is not prepared. The result is that data input is heavily smoothed to remove these departures from

the unexpected which would send the model out of control. The smoothing removes large changes which are real as well as the errors which are peak-values in noise. In effect the baby gets thrown out with the bath. When we least expect large changes, we are apt to call them errors or to smooth them out, but these large changes may be the key signals of the harsh things to come and they deserve to be verified in real-time. Therefore, when data departs so far from what is expected, the system should have the capability of finding out whether it is really an error which is being rejected, because it might not be.

Hindsight tells us that in Agnes, heavily smoothed low-level wind observations may have been the key to why the amount of moisture convergence in the weather system was missed. What is really needed is a feedback quality control system to provide the information on whether or not the unexpected reading is in error.

Initialization is not, of course, the only factor which makes mesoscale application difficult for the model. Scale-time is another. Radiosonde observations are now taken every 12 hours at 0000 and 1200Z. The models are "tuned" to accept data at these times. Twelve hours is, however, a long time interval for mesoscale phenomena. It is likely that more frequent radiosonde observations would have detected the cold pool south of the occluding storm, but one cannot justify doubling the observation costs to catch mesoscale phenomena is a net with low resolution. The real question is, "Would the predictions have been better if additional radiosonde ascents had been made: If so, how would one request them in special cases? If they were performed, would they do any good in the present system?" We know that much work is being done in order

to be able to accommodate non-synoptic data in preparation for the observing system to be used in the Global Atmospheric Research Program (GARP). Should we push this effort harder and faster so as to have this capability much sooner?

The radiosonde network is not the only source of data in the upper atmosphere. Could weather aircraft data have helped? These are but a few of the questions we could ask of the primary data system. We realize that in order to be able to use any non-synoptic data the models must be modified to be able to accept this kind of data. The number of observations which must be verified cannot be terribly large, but if the Agnes experience is any indicator it is terribly important to have this capability.

To recap: In our judgment information on the numerical guidance model furnished us hints that the apparent failure of all the models to reveal the true intensity of the storm may be due more to the initialization of the observed data in the analyzed fields rather in the models themselves. All the models have serious limitations on this space-scale but when these models are fed highly smoothed data which remove the intense storm indicators on the smallest scales, failure is inevitable. The second limitation is that at present the basic data gathering system does not have any feedback quality control system at all operating in real-time. Inclusion of such a capability in the first GARP, under consideration for 1977, might be implemented over the United States earlier than that. We recommend that this possibility be given careful consideration.

Verification by Satellite

There are other ways that one can ascertain whether the data and the forecast are to be trusted and that is to look at the big picture. Rather one has two big pictures. One is synthetic as revealed by the model, and one is the actual weather as revealed by the satellites, especially the geostationary satellites.

The synthetic weather evolves in the computer. The state of the real atmosphere as it evolves on the earth is revealed by geostationary satellites. In principle it should be possible to determine how the model is performing by comparing it with real weather on a time and space scale impossible to do any other way. A prognostic chart of the motion field at a particular satellite picture time is already available in the memory of the computer. At present satellites are not being used to provide quantitative "how goes it data." They easily could and should. We recommend that the feasibility of using geostationary satellite data as proof of performance of the model be carefully studied.

Getting More Out of Radar

River stage devices and rain gauges give one an accurate indication of what is happening at a specific location. To give meaning to these details one must be able to set these details into context. Radar coverage can help provide this picture because of its ability to locate storms via their rainfall over large areas. But clearly not enough is being got out of it. Interpretation of the signal characteristics are made at the local operator level. Rainfall location is easy, but

estimating rainfall amount is difficult to do unless one has suitable calibration information, sufficient training, and proper equipment -- this was discussed in an earlier chapter. The point we wish to make here is that the data return from a scanning radar set is prodigious. Unfortunately the quantitative information density is low and processing vast amounts of low information density data is not done well by humans. This is task ideally suited to a computer. The problem is the radar and computer tend to be at different locations. Fortunately technological developments make it possible to digitize the radar signals so the quantitative relationship can be preserved and also make it possible to compress the band-width so that communication requirements are relaxed considerably.

The digital radar attachment, D-RADEX, has some of these features. The system as presently configured is rather sophisticated and includes its own mini-computer. Outfitting all the radar stations with this equipment will take some time because of budget constraints. We suggest that a simpler version which retains the essential features needed for operational quantitative precipitation -- digitizing the signal so as to preserve the information and make it easier to transmit in its most conservative form, and transmitting it to some central computational facility -- be considered. It is more important to raise the level of all radar sets for better quantitative precipitation estimates than to develop the ideal system. Work done abroad shows that excellent precipitation estimates can be obtained with relatively modest digital

* "Digital Data Acquisition and Processing of Weather Radar Data," by G.von Kuers, Deutsche Luft-und-Raumfahrt Forschungsbericht, No. 70-32, October, 1970

It is essential to close the loop on quantitative precipitation observations at the hydrologists level. A way of communicating quantitative precipitation information to the hydrologist is essential, but he also needs a good feedback link to the operator to be sure of the observations. Technological development during the past two years in fast access digital data storage devices has been very substantial indeed. Since these storage elements form the heart of radar digitizing devices, the cost of providing this equipment is only a small fraction of the original investment in the high power radar set. Work done here and abroad shows that the utility of radar observations is enhanced considerably with these devices. We are therefore of the opinion that in places where rainfall quantity is critical it may be more important first to make this addition to present radar sets than to add other radar sets. Transmission of these quantitative radar signals to a central point for analysis will yield a significant increase in the "big picture" capability of the system as well as provide better quantitative information on the details for local use.

"Forecasting" and Flash Floods

River stage forecasting is based on upstream river gage readings and rain gage readings over the drainage basin. Forecast rains also play a role although not a major one. These data are fed into a computer at the River Forecasting Centers which produce river stage forecasts for various locations. All this assumes there is time to go through each step. Flash floods are defined as those occurring within four hours of the causative event and usually they are limited to tributary streams. Even in the best of circumstances there is an unhappy race between the

prospect of the event and its occurrence. In the case of Agnes in Pennsylvania and New York a number of factors combined to trouble the river forecasting units of NWS: major errors in forecasting storm behavior at a critical juncture; widespread long-lasting moderate-to-heavy rains which washed away gages and interrupted communications, and in some cases caused almost flash flood conditions on the major rivers; inadequate radar coverage over much of the area; inadequate quantitative precipitation forecasts; human limitations; saturated communications systems.

The combination of all these things left the river forecasting service barely able to stay ahead of the river stages with their forecasts and in some cases the lead-time between the forecast and the event was negative. Though the dedication and perseverance of the river forecasting staff came close to making a win out of a loss, and without question their work was instrumental in saving many lives and much property, it was too close a shave to leave anyone feeling comfortable.

In fact, upon reading NOAA's Disaster Team's report on the performance of the rainfall and river gauging network, one can only conclude it was badly mauled in the crisis and it was to the credit of the human performers that they could get the system to transcend its loss.

Where can technology help? The task of sensing the parameters needed for river stage forecasting--current river level and what rain is falling where--is almost a trivial task for technology. Collecting these observations and making sure they will be available, even in an emergency, may be more challenging; but it is hardly impossible technologically. The existing network was damaged but one should resist the

temptation to put back what was there simply to fill the now serious gap (though time to repair vs. replace must be balanced against the risk of being caught unprepared). This will provide the opportunity to state the real requirements of the rainfall network and river gauging network. It is conceivable that the multiple-use and multiple-support basis of the old system must be abandoned and it is certain that reliability of operation is a basic requirement especially for an automatic telemetry system. Also, many simple systems are to be preferred over a few sophisticated ones. Not only will this yield better areal coverage but will provide badly needed redundancy. Certainly any new system must telescope the many time-consuming steps at present in hydrologic forecasting into fewer and faster ones. This is an especially important requirement for flash flooding.

The panel therefore sees the need for two clearly distinguished types of river observations.

- (1) Those needed to understand the behavior of the river under typical conditions. Here one needs some water level recording to establish the "hydrograph" as a function of many conditions.
- (2) Those needed for warning of an emergency. These instruments can be go - no go devices, but must have extremely high reliability. They need not even be at the river's edge. This is not the place to suggest instrument designs but there seem to be many ways to devise these instruments so they ignore everything EXCEPT being several feet under water.

The use of a computer for river forecasting should aid the whole forecast process - be more accurate - get it out on time. However, when the computer is inaccessible due to communication or power outages or at times when it is shut down for other reasons, reliance on the computer is a burden. River stage forecasting to a foot or so during normal conditions must be satisfying but when the prediction is missed by several yards in an emergency the elegance provided by the computer is of little value when it counts.

But having a computer allows one to do experiments. Call them "if it's" experiments. That is "if it" rains this much then such and such will happen. Look-up table--kept current-- could be made available as a quick reference in an emergency. Lead-time is very precious and any scheme that might yield some lead-time should be carefully investigated. As in other areas, reliable communication is vital. If it is possible to place the user and the data in close proximity, this should be done. We understand that NWS does this in some circumstances. The value of more immediate widespread use should be examined.

Internal Dissemination and Communications

It is easy to identify two important information-dissemination needs. One is internal to the system (though it could include contact with public officials who are responsible for public safety) which we will discuss here briefly. The other, communication of the forecast or warning to the public, is external and will be discussed in the next section. The real deficiencies in internal communication in the system can be corrected as a matter of urgency because of recent rapid

technological developments. Many of these ideas for improvement of internal communications are not new. They are the grand ideas of a few years ago. The key point here is that, thanks to recent developments in technology, they are possible now at surprisingly low cost.

The present communication system hardly more than meets the needs for day-to-day activities and in an emergency is bound to be severely overtaxed. In a typical weather station a battery of teletypes clatters away continuously. On a typical day roughly 30% of the station personnel's time is consumed just treating the teletype data. Anyone who has visited a station is familiar with the many sheets of yellow paper on a board of clips. In addition a facsimile machine is also producing maps of a wide variety. The station, especially at peak periods, is hard put to keep up with the data flow and requests for information. During severe weather the demands increase dramatically. There are more observations to be taken, more phone calls to answer, more teletype slips to file, more contact with higher offices, etc. Thus during an emergency when weather information, not data, is needed so badly, the typical station is definitely over-taxed. The local station is at the receiving end of a large but cumbersome network. It is not able to make many specific requests even when there is a need for specific information. It is ironic that the local meteorologist could walk to a different part of the airport building and request a seat on a given flight on a given day and know its availability in a few moments. In many ways air reservation update, though admittedly with simpler requirements, is a similar data processing problem to his, but all the meteorologist can do is wave his arms.

We recommend that the internal information dissemination capability be treated as a system and that system design take into account the emergency situation requirements. It is not too much to say that there is a need for examining the very assumptions, requirements, and technical feasibilities in information flow. This is not the place to detail any of the possible approaches that might be used but it is clear that the opportunities are manifold.

We concur with the NOAA Survey that many of the problems of effectiveness occurred in the hand-off from the Weather Service to outside agencies. No matter how it solved its technical problems of observation, forecast, assessment, and decision to warn, no one quite seems in charge of the store when it comes to making sure that the meaning of the message which is sent, is the same as the meaning of the message which is heard.

Some of the difficulty is technical (or economic) in nature, but much of it is not. It is this difficult area of external dissemination of the warning, the we take up in the next section.

EXTERNAL DISSEMINATION, PUBLIC RESPONSE, AND PREVENTION*

The final test of a warning system is the extent to which in practice it induces optimal behavior by those who would benefit from receiving the warning. In the case of Tropical Storm Agnes we note that the evidence on which a judgment of the warning system can be

* These observations draw upon tentative findings from the Assessment of Research on Natural Hazards currently in progress at the University of Colorado with support from the National Science Foundation.

based is lacking in part -- especially on the effectiveness of external dissemination. This deficiency and the accompanying difficulty in appraising the activities during Agnes can be traced to two long-standing limitations upon the National Weather Service: 1) it has not been given budgetary support in efforts to deal with the whole range of measures that are required for an adequate warning system, and 2) it lacks effective linkage with several other sectors of Federal, state, and local programs which also influence human response to flood situations.

Essentials of a warning system

A warning system should be viewed as a combination of technical and social arrangements which provide opportunity for individuals and groups affected by a flood to respond in ways most beneficial to them. The benefits include preventing loss of life, preventing injury, reducing property damage, and reducing social disorganization. All of these result from specified behavior on the part of private individuals and public officials. In the case of loss of life or limb, a system can be completely effective but cannot guarantee losses resulting from irresponsible and venturesome behavior of those warned. In the case of property loss, as much as 25 percent of damages in urban areas may be prevented by emergency measures alone, and larger amounts may be saved if warnings are linked with prior flood-proofing measures.

Less is known about the conditions for effective design and operation of a warning system than about delivery systems for emergency relief,

but a few generalizations can be drawn from the experience of recent years. It is known that response can be influenced in a variety of ways, chiefly: 1) training of people to act upon their own observations of natural phenomena, such as river stage or heavy rain; 2) organizing for action to take place whenever pre-arranged signals such as sirens are received; 3) issuance of a warning, as with radio announcements; 4) directions for action transmitted as part of a warning; and 5) forced evacuation where public agencies require specified actions by groups of citizens.

In the warning systems which were in operation during Agnes principal reliance was placed upon the issuance of warnings to selected agencies and media which were expected to transmit the message to people concerned. There, as in most similar arrangements, a number of assumptions are made. It is assumed that 1) messages will be transmitted with no important change; 2) the recipients will understand the message as intended by those issuing it; 3) the recipients will know what to do in their own best interest after receiving the message; and 4) all people concerned will receive the message. Rarely are all these conditions fulfilled, and clearly not in many areas affected by Agnes.

It also is known that people process information as to an impending hydrologic event in different ways, as when some will accept a forecast only after having confirmed it with neighbors. These differences can be traced in part to the precise form of the message, its content, and the authority with which it is disseminated. They also reflect the prior arrangements to specify a) hazard areas, b) steps to be taken in the event of an emergency, and c) the responsible public authorities.

Two groups of people can interpret the same message differently, and even if they share the same interpretation one of them may know what to do while the other group is confused and ineffective. Thus, a homeowner warned to evacuate his house either may leave it highly vulnerable to damage or may curb losses substantially by disconnecting heating systems, elevating certain equipment, and stacking furniture before he locks the door behind him. If a warning is issued, but no single public agency feels responsible for assuring response to it, little action may be taken.

In most situations an adequate warning must be transmitted through several channels in several forms to reach all affected groups. Most public officials in flood hazard areas will assert that they have a warning-system, knowing that they can look to NWS for forecasts, and to radio and TV for broadcasts. However, there has never been a thorough investigation of precisely what would be required in particular communities and of how the system works when put to a test. For example, without such inquiry it is impossible to estimate what effects radio broadcasts have had. This investigation must take account of differences in interpretation, the information and actions available to recipients, the variety of channels through which information can be transmitted, and the factors such as age, experience, education and economic situation which will affect individual adoption of a particular action. The capacities of communities to develop adequate warning systems on their own are affected by population size, financial resources, linkages with media, use of radio and TV sets, police-citizen relations, frequency of

extreme flood events, willingness of officials to risk false alarms, state-Federal relations, and organizational capacity. No wonder that public response varied so widely from community to community during the Agnes floods.

The linkages involved in the action taken by a single homeowner in a flood plain may be charted as shown in Figure 2. In addition to whatever cues the homeowners may be trained to use from their own observation of rain or stream, they are subject to verbal messages from media and agencies. They do not ordinarily receive signals or instructions unless forced evacuation is believed necessary. Thus the warning activities during Agnes did not involve a number of actions which were possible and would have been effective in reducing losses.

A warning system is only as good as all the links in the several parts of the system. The perfect forecast will have no benefit if it is not disseminated to users who are prepared or instructed to take appropriate action. Contrariwise an elaborate emergency plan within an industrial plant will be fruitless unless the forecast reaches the right people in sufficient time.

The well-designed warning system that functions effectively sends out warnings as soon as the meteorological-hydrological analysis permits. But it does not rely wholly on such warnings. It has trained individuals to make their own observations, and in flash-flood situations, it has built local community ability to do so without having to wait for a regional forecast. It has specified the areas to be inundated by given levels of flooding, and it is sure that these

are known to the people affected. It has joined in cooperative examination of the kinds of action, both individual and community, which those people can take to their benefit. It includes with the warnings whatever instructions are helpful. It knows what form of message and what channels are likely to reach people. Releasing a forecast to the media is only one and sometimes a minor part of the whole system.

Against these criteria, the Wilkes-Barre experience comes closest to an ideal performance during Agnes. The existence of a vigorous civil defense organization, closely linked with municipal authorities and headed by a person who normally served as a river stage observer, provided large organizational capacity to respond to a warning. The length of lead-time, about 10 hours, the unambiguous need to carry out complete evacuation of the area protected by the levee which was to be overtopped, the prompt mutual confirmation of warnings, and the clear delimitation of the area protected by levees enhanced the probability that all affected people would respond promptly and uniformly. In practice, they did. All forms of dissemination were employed in an interlocking fashion, and the record of forced evacuation is solid. However, there is no record of the extent to which individual action between receipt of warning and completion of forced evacuation reduced the property damage which was incurred when the levees broke.

The problems of dissemination were far more complex where the threat of levee collapse was absent or less likely, where the area at risk was not delimited, and where individual householders had more choice as to what they could do. In forecasting flash floods

the difficulties in defining the affected area are great and the magnitude of flooding can be specified only within a broad range, so that the recipient of a message must use large discretion in deciding what to do. But even in dealing with floods with a longer flood-to-peak interval it is often fruitless to issue a warning if the area at risk is not defined and if the recipient is unprepared to act.

NOAA currently has no funds with which to examine the broader aspects of the warning systems of which its river and flash flood forecasts should be the key part. It does not have enough personnel with primary responsibility to deal with problems of disseminating the forecast to the user. And it carries out no research on those problems or ways of preventing them. It should, because no other agency can do this for them.

Warning Benefits: Decreased Loss of Life

The primary purpose of the flash flood warnings during Agnes as in other flash situations was to save life. For the ordinary river floods with longer lead-times, it is rare that a warning has a positive effect in preventing loss of life: the variation in number of deaths would be likely to occur with or without formal warnings. Spectators crowd a crumbling bank. Families stroll along a swollen stream and fall in, as in Rock Creek Park in Washington. Daring salvage operations risk life in swift currents, as at Painted Post.

On the basis of opinions collected from field observers, there is evidence that in only a few situations would lives have been saved during Agnes by improved warnings. Probably the one major set of deaths which might have been prevented were those to people stranded in automobiles which were driven into deep water on highways. Greater flow of information about these risks and how to avoid them at the time warnings were issued might have helped, and use of such information as part of the warning should be considered for the future.

However, it should be remembered that in many flash floods, such as Rapid City, substantial losses could have been prevented had warnings reached people a few hours earlier. Without time, the cupboard of alternatives is really bare.

Warning Benefits: Decreased Property Loss

The Corps of Engineers and the Soil Conservation Service have estimated property losses prevented by the operation of protection works in operation or which might have been prevented by works under construction. These estimates are made by referring to stage-damage curves which were computed when the projects were authorized and which show likely dollar losses at various levels of flooding.

The estimates do not show the actual damage and do not indicate what part of the potential total damage in fact was prevented by actions related to the warning system. There is no systematic arrangement for examining the potential and actual performance in selected river reaches in order to calculate what could have been damaged and what was experienced.

Thus, the NWS lacks any solid base for calculating the monetary benefits from its forecasting services, and the other agencies do not know how much their activities were enhanced or handicapped by operation of the warning system. The lack of such information clearly hampers development of those aspects of a warning service which cost/benefit analysis could support.

Warning and Other Programs

Under the Federal policy of managing flood losses as presented in House Document 465* flood warnings were seen as one essential tool in a kit of management devices available to Federal, state and local agencies as well as to private property owners. The other tools include:

Flood control and protection works

Flood-proofing activities

- a. Independent of warnings
- b. Dependent upon warnings

Flood insurance

Flood plain management

- a. Acquisition programs, e.g., for
parks and urban renewal
- b. Subdivision regulations
- c. Zoning ordinances
- d. Building permits
- e. Utility extension controls

Relief and rehabilitation

*"A Unified National Program for Managing Flood Losses", A report by the Task Force on Federal Flood Control Policy, submitted to the 89th Congress, 2nd Session, August 10, 1966.

All of these require flood plain information designating hazard areas, flood magnitude, flood frequency, and alternative measure.

In any given flood plain these several tools are interlocked in intricate ways. A few may be noted. A completed protection work can engender apathy toward flood risk, as was reported by some observers at Corning. Flood insurance can be a tangible reminder, especially if required by mortgage agencies, of risks and of ways of averting losses. Land use management can direct new land uses into less vulnerable areas or into forms that minimize losses. A generous public assistance policy toward loan rates and forgiveness can encourage residents to return and seek hazardous exposure. There is no single, most efficient mix of these measures: it varies with the situation. However, there is no doubt that unless the whole range of alternative measures is canvassed carefully, undue reliance will be placed upon one measure to the exclusion of others, and that disaster will be courted.

It is no accident that mean annual flood losses in the United States have risen persistently since the first national flood control act was passed in 1936. The net effect of the measures promoted by the Federal government under that policy in the ensuing 30 years was to reduce losses in certain areas while encouraging further encroachment in other areas. The possibility of catastrophic failures was enhanced rather than reduced. The new policy now is getting into action but it has moved slowly since 1966, and current assistance programs threaten to undermine it. No forecasting and warning system, however, effective, could compensate for unrestrained and improper development of the flood-plains.

To show some of the effects of the current programs in action, we summarize the present situation in seven urban areas which suffered serious damage during Agnes. Together they account for a significant portion of the total damage. For each we indicate the extent of estimated reconstruction costs, and the status of:

flood plain information

control disaster organization

community disaster organization

land use regulations

flood insurance.

From these examples it is apparent that improvements in warning activities will only be assured of being effective if linked with other programs for managing flood losses and flood plain use.

As shown in Table I only one of the seven areas was covered by a complete Flood Plain Information Report at the time of Agnes, and two of the areas (Pottstown and Wellsville) have no plans for such reports giving essential information on hazard areas. Only one area (portions of the Washington metropolitan area) has enacted regulations of further land development in the flood plain. For that reason, it was the only one where insurance had been sold. Wilkes-Barre, with minimal building permit controls, had become eligible for insurance in December, 1971, but there have been only three sales. Thus, the homeowners in the greater part of these cities had no occasion to consider their flood risks or ways of reducing premiums in connection with insurance. In four of the areas Federal protection works were overtopped by Agnes flows, calling attention to the difficulties of

Table I

SUMMARY OF FLOOD HAZARD SITUATION IN SEVEN SELECTED URBAN AREAS

	Area						
	Richmond, Virginia	Washington Metro	Wilkes-Barre, Pennsylvania	Corning, New York	Pittsburgh, Pennsylvania	Wellsville, New York	Pottstown, Pennsylvania
OEP Rough Estimates of Relief Reconstruction \$ Million	42	5	780	330	11	33	86
Hazard area	Sections of urban area	Small streams outside of D.C.	Densely settled	Densely settled	Densely settled	Sections of urban area	Sections of urban area
Flood Plain Information Reports	Completed 1967	7 completed 2 underway	Underway	Not started	Underway	None	None
Control and Protection Works	Small levees (overtopped)	Levee in D.C.	Levees (overtopped) protect from 1936 flood of record. Reservoirs proposed	Levees (overtopped) protect from 1946 flood of record. Reservoir underway	Reservoirs reduced flood 12 feet. Additional proposed	Channel and levee (overtopped) protect from 1950 flood of record.	None
Community Disaster Organization	Plan used	Plans used in part	Plan used	No plan	Plan not used	County plan used	Obsolete
Land Use Regulations	Being developed	Part Some very detailed	Minimal	None	None	None	None
Flood Insurance Policies sold as of July 31, 1972	Not eligible	Partly eligible 433 policies	Eligible 3	Not eligible	Not eligible	Not eligible	Not eligible

operating a warning system where physical works encourage inhabitants to believe they are protected from floods even though the authorized designs were for flows much smaller than generated by Agnes. One of the cities had no effective disaster plan, another did not use an outmoded plan, and in a third the plan was long since obsolete. The warning operation must be assessed in the framework of past Federal policies which encouraged complacency and an inclination to rely either upon Federal protection or Federal relief.

In conclusion: It is clear, and experience with Agnes confirms it, that effectiveness of a warning system, which by definition includes problems of how the public responds, is affected by aspects which are no single agency's responsibility, are not well understood, are complex, but are nevertheless critical.

We believe that NOAA must reach out and make certain that its messages are understood, i.e., to make sure that its effort to improve its forecasting and warning capability is not negated by poorly understood dissemination practices. The whole burden of a disaster warning system effectiveness does not rest upon NOAA. But what NOAA does must be consistent with what is being discovered in other areas of emergency planning and it is NOAA's responsibility to sense how well people understand what should be done when it issues its watches and its warnings. We believe the Weather Service should have the capability of monitoring the state of readiness of people to react

effectively to disaster warnings. Its forecasting services are of considerable benefit to other agencies as well as to the general public. If more were known of the benefits of particular aspects of the warning system, the Weather Service would be in a better position to enlist support for their further development when needed.

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