General Quick Advice to Consultants: Using WBNM2017.

INTRODUCTION to WBNM:

Wollongong City Council officers are often in positions of reviewing hydrologic models prepared by consultants. Through this process it has discovered several at times alarming uses of the WBNM model and setting of its parameters that are questionable and certainly not in line with the latest recommendations from the model authors.

It would appear that in a great many cases WBNM is being USED, or somewhat abused to feed local hydrographs into 2D models that otherwise struggle or are incapable of utilising Rain on Grid techniques. Through this practice the industry is complicit in advocating extremely poor practices and outcomes for our communities.

This short document URGES that this practice cease and WBNM be used as it was designed. This document aims to justify building connected hydrologic model as a very viable way to use WBNM to ensure the hydraulic modelling is done in the best possible way with a means of confirming flow response from catchments at various locations within the catchment.

WBNM has only a limited number of ways to change how it replicates catchment response:

- Adjusting the Rainfall input via rainfall losses
- Adjusting the runoff response by adjusting the Area and Stream Lag
    - Noting that % Impervious adjust this also (This was not the case in older versions)

A modeller's job is to select those parameters to most accurately reflect the catchments response as realistically as possible, ensuring you can logically justify the parameter selection. Stating that this is what others have used in the past, is inadequate justification.

The "traditional" and current "industry standard" approach of using two independent models (Hydrologic and Hydraulic) to complete flood studies could benefit considerably by fully utilising the capabilities of WBNM properly and fully. As without a fully developed hydrologic model there is no way to provide a comparison as to the performance of the hydraulic model.

To adjust parameters and use the results of one independent model (hydrologic) as input into a second independent model (hydraulic) which requires the user to change parameters in it to calibrate to a flood level or stage gauge is downright dangerous and senseless; as it is often the case that errors in three parameters can still produce a reasonable calibration (but be totally wrong).

WBNM provides an easily developed sanity check model even to the most complex of hydraulic models.

- WBNM provides a very useful fast method to check and compare results of your Hydraulic models if you include connectivity and storages.
- In most cases WBNM can model and replicate the results
- Usually if there is a significant difference, it is due to a storage not being included in WBNM

In preparing a hydrologic model firstly; READ THE LATEST APPROPRIATE MANUALS ; in case any of the methods within the model have changed. (Some of which have change critically in WBNM since it first inception for example). {A key example is the addition of Impervious % so as to no longer need the adjustment of the "C" Parameter for every sub area.} Hence older models are not compatible for running with the current engine unedited.

Lets get to the guts of it:

The Watershed Bounded Network Model WBNM arose out of a Master of Engineering Science project by Michael Boyd, supervised by David Pilgrim in 1973. This was further developed into a PhD project, under the supervision of David Pilgrim and Ian Cordery. The

The first version of WBNM was released in 1979 and was 145 lines of CODE, the 2017 version is in excess of 40,000 lines of CODE.

Since 1973, WBNM has developed considerably, and although the BASE MODEL equations have not changed the Parameters that drive them and how they are driven have and it is important to recognise this and respond to it ! Yes the Australian Gods of Hydrology developed this model and it does a remarkable job replicating catchment response, BUT… Rubbish IN = Rubbish OUT !!!
The aim of the modeller is to provide the best reflection of the catchments response to rainfall.

WBNM in reality is a very, very simple model.

WBNM can be considered and visualised as a cascading storage model, as if it were a series of cups as it were. There is at least 1 cup for every sub area, but there can be 2, 3 or 4 as follows:

- 1. Head Area (Sub Area Flow) only [1 cup] (well two half cups pervious and impervious)
- 2. Linking Sub Area (Sub Area Flow + Stream Flow) [2 cups]
- 3. As above(2) with a Local Storage (OSD) [3 cups]
- 4. As above (2) with an Outlet Storage (BASIN) [3Cups]
- 5. As above (2) with both Local and Outlet Storage [4 Cups]

WBNM ALGORITHMS:

- The equations that describe the cups are all derived from equation 1 below (All of the material below comes from the USER MANUAL and THEORY documents):

The equations in WBNBM are:

For each subarea, Conservation of Mass

$$I - Q = dS / dt \qquad (1)$$

where I = inflow rate at time t (m^3/s)
Q = outflow rate at time t (m^3/s)
S = volume of water stored on catchment surface at time t (m^3)
t = time (s)

The stored volume is related to the outflow discharge by

$$S = 60.\ K.\ Q \qquad (2)$$

$$S = K.\ Q = k.Q^{m}$$

where K = lag time between centroids of inflow and outflow hydrographs (minutes).

The lag time K will depend on the size of the subarea. If it remained constant for this subarea for all size floods, the model would be linear (similar to the Unit Hydrograph). However, based on recorded rainfall and flood hydrograph data (Askew, 1968, 1970), and also on hydraulic considerations, WBNM allows K to decrease as flood discharges increase, and is thus nonlinear.

The Storage is intrinsically linked to every sub area in three ways:

- And an Overland Flow Lag
- As a Stream Lag
- As a specific Storage (Basin)
-

$$\text{Overland Flow Lag Time} = \text{Lag Parameter}.\ A^{0.57}.\ Q^{-0.23} \qquad (3)$$

(A km^2 ; Q m^3/s ; Lag Time hours)

$$\text{Impervious Surface Lag} = \text{Impervious Lag Factor}\ .\ \text{Lag Parameter}\ .\ (A.IMP/100)^{0.25} \qquad (6)$$

$$\text{Stream Channel Lag} = \underline{\text{Stream Lag Factor}}\ .\ 0.6\ .\ \text{Lag Parameter}.\ A^{0.57}.\ Q^{-0.23} \qquad (5)$$

(Note that the Lag Parameter C is in both the Surface & Stream lags)

Storage Reservoirs (OSD & BASINS) are routed using the Modified Puls method:

After 44 years of Research the advice on the Lag Parameter is:........

Considering all of these results, a value of the **Lag Parameter near to 1.6 is recommended**. It is, of course, desirable to check the results of any model against recorded flood data. This will preferably be a recorded hydrograph, but peak flood levels could also be used.
The impervious area on the subarea is A.(IMP/100) where IMP is the impervious percentage. The same Lag Parameter as for pervious surfaces (ie a value between 1.30 and 1.80) is used, but is reduced by the Impervious Lag Factor which has a recommended value of 0.10.

In some subareas, runoff from upstream subareas flows through the main stream channel. WBNM calculates separate hydrographs for the channel routing and for the overland flow routing on these subareas. This is a physically realistic approach, because flow velocities and lag times will be different for channel flow compared to overland flow. Also, this approach allows modification to catchment surfaces (eg imperviousness) separately from changing to stream channels (eg clearing, lining).

Because WBNM allows adjustments for impervious surfaces, and for modifications to stream channels, this base value of the Lag Parameter should apply to natural, part urban and fully urban catchments. **The same value of the Lag Parameter should be used for all subareas (global value), unless there is good evidence for varying it.**

This text is Extracted directly from the current Manual

Further;

Lag times for runoff (strictly defined as the time difference between the centroids of the excess rainfall hyetograph and the surface runoff hydrograph) depend on the physical properties of the catchment. These include area A, shape (often defined as A/L^2) and slope for natural catchments. For urban catchments, the effects of impervious surfaces and modifications to stream channels should be included. Catchment flood response is often considered to be nonlinear, with lag times decreasing as the size of the flood increases.

WBNM also allows modification to the form of the nonlinearity. It is sometimes considered that whereas small to medium floods behave nonlinearly, larger to extreme floods may behave linearly (Bates and Pilgrim, 1983, 1986; Wong and Laurenson, 1983). WBNM models this by allowing you to specify a discharge at the catchment outlet above which the response changes from nonlinear to linear. As discharges are calculated during a flood, WBNM automatically decreases the lag time at each time step, according to equations 3 and 4. When the discharge exceeds the specified value, WBNM retains the last calculated lag time for all subsequent calculations (and so remains linear), until the discharge falls back below the specified value, when nonlinearity resumes. In WBNM, the specified nonlinear/ linear breakpoint discharge at the catchment outlet is automatically adjusted and applied to all points within the catchment. This is done by factoring this discharge by the square root of the ratio of area contributing to the point, over the total catchment area. For subareas 1, 2 and 4 in figure 1, this area is for the subarea itself. For stream channels (subares 3 and 5), it is the total area upstream of this point. The SUM_SUBAREAS table gives the area and running (ie cumulative) area at these points, plus these adjusted breakpoint discharges. Note that this table only shows the breakpoint discharges for runoff from the subarea itself (and are thus based on the subarea size alone), and not for the stream channel using the total area upstream of this point. The breakpoint discharges calculated for the stream channels are not shown.

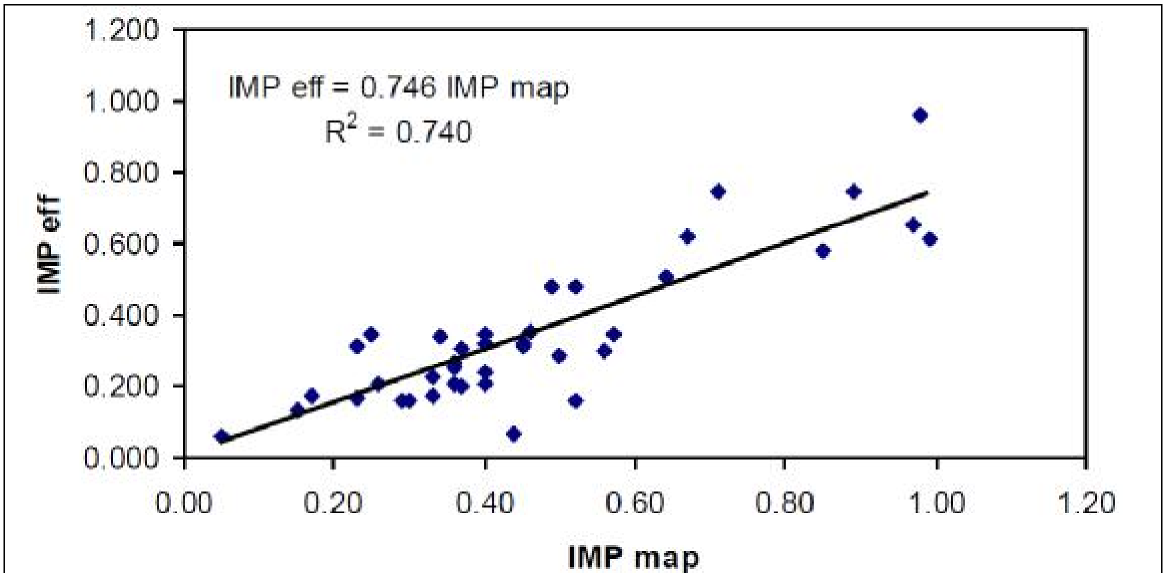
We strongly recommend that you run WBNM as fully nonlinear (with m-1 = -0.23) unless you have good evidence that a change from nonlinear to linear response occurs.

This text is Extracted directly from the current Manual

Process for Setting Parameters:

Firstly ignore what others have done in previous models, use your own logic and the model manual advice applied to current catchment data.

- Start with a Catchment Wide Catchment LAG of around 1.6 (unless you have clear evidence to change it. Noting that all research to date has put the base parameter between 1.3 & 1.8 and current overall average and recommended value of 1.61.)
- Urbanisation is accounted for by the % EFFECTIVE impervious surface (not exact % impervious surface) and by adjusting the stream LAG.
- Remembering that WBNM was originally developed as a NATURAL Catchment model with the streams assumed to be "Natural", (Twisting and vegetated etc.)
- If a stream is not "Natural" then you need to review the Stream Lag from the Natural value of 1.0 to account for the increase in flow velocity.
- So if a stream is straightened and has natural vegetation partially or largely removed, then the velocity in the stream is likely increased from its natural state and requires the subsequent reduction in stream lag. If the velocity has changed from 1.5m/s to 4.5m/s then the lag reduces from 1.0 to 1.5/4.5 = 0.33
- Refer to discussion of impact of changing parameters below
- The ability of WBNM to model storages is very powerful easy check of flood levels albeit at only specific locations.
    - The derivation of Stage Storage Curves and basin flow control structures can provide surprisingly accurate estimates of flood levels at for example road embankments.
    - This also allows some limited diversion of flow
        - Noting that the proposed WBNMts (time step) model will allow much more flexibility with diversions.



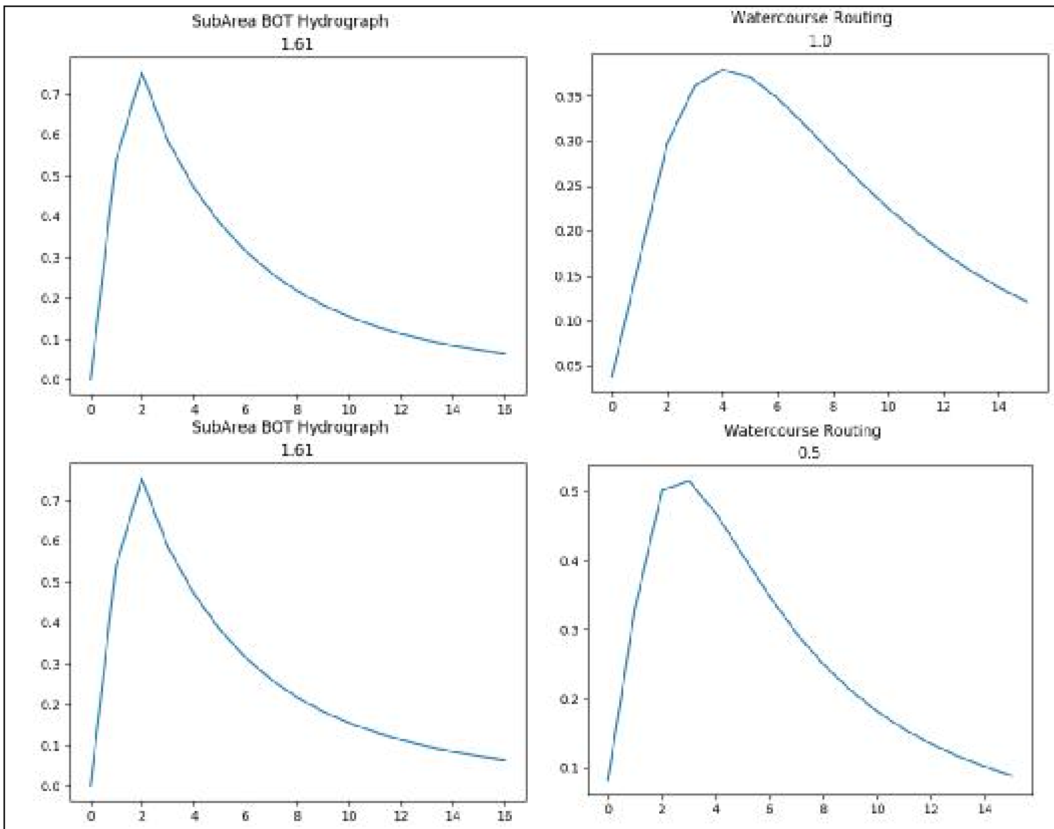
Assessing Effective % Impervious from Actual % Impervious from maps

IMPACT OF VARYING PARAMETERS:

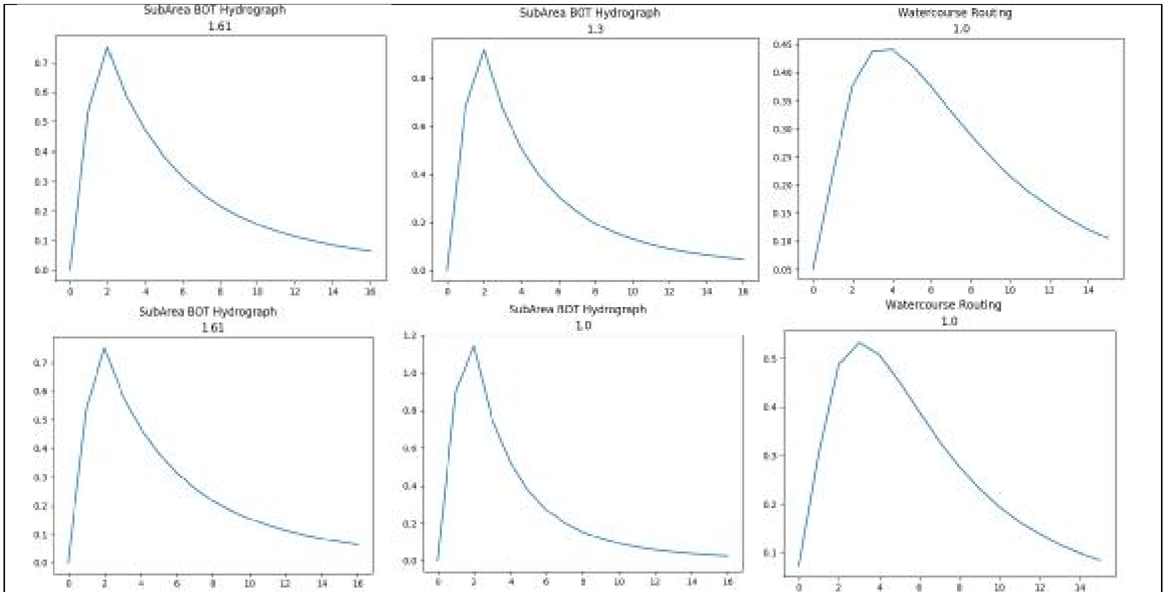
When trying to calibrate models and attempting to match recorded shapes of catchment response it is useful to know what the parameter changes physically mean and what it does to your results.

- CATCHMENT (Sub Area) LAG "C"- Parameter:
    - The "C" parameter is the Primary Parameter that impacts ALL aspect of hydrograph shape in WBNM
        - It effects the Local Area Runoff LAG
            - Both pervious and impervious
        - It effects the Stream Lag also
    - What it physically means is that there is MORE or LESS dynamic storage Volume
- STREAM LAG
    - Once again this parameter adjust the volume of dynamic storage allocated to a stream segment in a sub area
- % Impervious

Pouring inflow through storage volume, adjusts the shape of the hydrograph in two ways. It affects the value of the peak, and it effects the time at which that peak occurs.

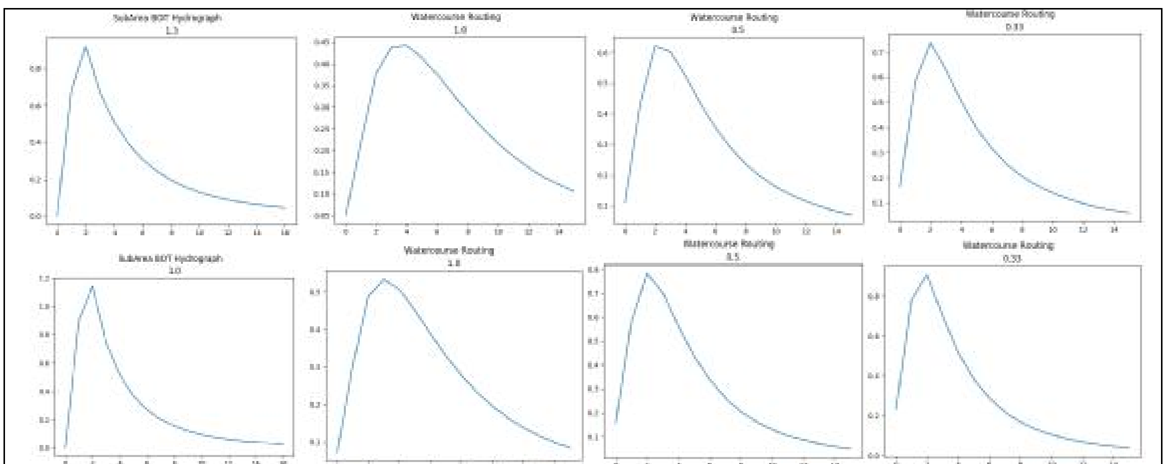


Impact on WBNM hydrograph Shapes from changing only Stream Lag (1.0 à 0.5)
Peak Flow increases from 0.36 à 0.52m3/s



Impact on WBNM hydrograph Shapes from changing only Sub Area Lag (C-Param) {1.61 à 1.3 à 1.0}

The Area Lag reduced from 1.61 to 1.3 and then 1.0 increases the flow from 0.75 through 0.92 to 1.14m3/s.



Impact on WBNM hydrograph Shapes from changing Sub Area Lag (C-Param) and Stream Lag

The above shows that various combinations of "C" and Stream Lag can result in an identical sub area producing flows varying from 0.36 through, 0.44, 0.52, 0.60, 0.78 to 0.90m3/s, with identical flow volume.

	Impact on FLOWS of Changing WBNM PARAMS								
C- Param	1.0			0.5			0.33		
Flow à	0.752			0.918			1.144		
Stream LAG	1.0	0.5	0.33	1.0	0.5	0.33	1.0	0.5	0.33
Flow à	0.42	0.56	0.641	0.50	0.687	0.773	0.602	0.856	0.939

In General making the sub Area Lag Parameter smaller makes a higher peak arrive earlier, whilst similarly reducing the Stream Lag also makes a higher peak arrive earlier. Increasing the % impervious also results in a higher peak and earlier peak time.

SUMMARY : IMPACT OF VARYING PARAMETERS:				
	Increase Value of Parameter		Decrease Value of Parameter	
WBNM Params	Value of Peak	Timing of Peak	Value of Peak	Time of Peak
SubArea LAG	Lower	Later	Higher	Earlier
Stream LAG	Lower	Later	Higher	Earlier
% Effective IMP	Higher	Earlier	Lower	Later

A Warning about Sub Areas with large Storages:

If a sub area contains a large Storage basin or a Lake for example, then it is incorrect to assume that the lake is part of the sub area as there will be LAG assigned to the area or total area. It is more correct to assign the Surface Area of the Lake in the definition of the Storage so that the response is linear as defined in the Manual. This is possible by making the Sub Area a "DUMMY" area with an area of ZERO.

The surface area of the storage can be specified, and WBNM adds any rain falling on this surface area directly into the inflow hydrograph. If you allocate a part of the subarea's total area to this surface area, you may wish to deduct the value from the total area of the subarea in the SURFACES block of the runfile.
This text is Extracted directly from the current Manual

Note this approach is not 100% correct if the surface area of the storage changes as the water level changes. This aspect of WBNM is being addressed in the NEXT RELEASE of WBNM where it will determine how much of the sub area is underwater. WBNM will also be changed to a Time Step Model as the primary loop rather than the current Sub Area loop being the primary loop. The Time Step model will also allow multiple sub areas to be drowned out by back water, a feature not currently available. In addition a time step model will also allow redirection of flow anywhere, even up the catchment such as pumping for example.

Proven Efficient Modelling Practices:

Setting up a hydrologic model for the specific purpose of feeding local hydrographs into a hydraulic model is an exercise that can at times include many 1000's of sub areas, making the process cumbersome and complex. This is particularly the case when there is a requirement to adjust input parameters. Hence it has been found that often the initial hydrologic model is rarely revisited to adjust or improve the model. Instead parameters in the hydraulic model are adjusted (sometimes beyond reality) to improve calibration. This is seen as a particularly poor practice.

There is an alternate approach which assists in making the process considerably more efficient and flexible. This is particularly made efficient with GIS tools where by polygons can be used to select other objects inside sub catchment for example.

In order to easily and efficiently get a good handle on catchment response and also streamline and make working with large numbers of sub areas (to Drive 2D hydraulic models) much more efficient, the following approach has been proven to be very effective:

- Initially build a relatively coarse model that is easily managed
- Suggesting no more than say 50 sub Areas
- Set the Global "C" parameter to the recommended value of 1.61
- Make specific assessments of;
    - % Effective Imperviousness
    - The condition of the watercourse segments in the sub areas as compared to a TOTALLY NATURAL one
    - Set the Watercourse Lag Parameters for those Sub areas
- Include any known significant storages
- Assess any calibration data that may be applicable to a Storage such as stage cauge at a roadway embankment
- Include the recorded data in the WBNM runfile
- Assess calibration Rainfall and Climate Data
- Make any adjustments to rainfall weighting if necessary to account for Climate data such as for example a Strong Southerly wind?
- Adjust Rainfall Losses, to initially compare Hydrograph Shape to Recorded Data
- If there is any significant difference go back and confirm % Effective Imperviousness and Stream Lag, accounting for the impact on hydrograph shape as discussed above.
- Once a well calibrated Hydrologic model is attained, build the fine model with how ever many sub areas required (1000's ??) and use the Coarse model parameters to set the fine model parameters.
- Adjusting the parameters for all of the smaller sub areas contained with the larger sub area of the coarse model is relatively easy with GIS tool.
- On this basis the fine model should be the best starting position for a sound modelling approach.

There are very significant benefits to following this procedure.

IF YOU USE A MODEL, READ ITS MANUAL: { Essential for WBNM 2017}

WBNM THEORY (45 pages)

WBNM USER GUIDE (29 pages)

WBNM RUNFILE (23 Pages)

WBNM HISTORY (3 pages)