At What Aperture Will Diffraction Degrade Image Quality?

When we stop down our lenses (going from f/4 toward f/22, for example), Depth of Field is increased, improving sharpness in those areas of the subject space that are farthest from the Plane of Sharpest Focus, but Diffraction is also increased, softening the entire image, independent of subject distance. There is a point at which the gain in image clarity had by stopping down to improve Depth of Field will be overwhelmed by a loss in image clarity caused by Diffraction.

The aperture at which the effects of diffraction become visible in the final print can be obtained by working backwards from your anticipated enlargement factor and desired resolution at the print.

Maximum N = 1 / desired print resolution / enlargement factor / 0.00135383

Where do we get the constant 0.00135383? See the section on Diffraction in David Jacobson's Lens Tutorial:

http://www.photo.net/photo/optics/lensTutorial.html

Most people agree that the average adult with healthy vision can resolve no more than about 5 to 8 lp/mm (line pairs per millimeter) at a viewing distance of 10 inches. Assuming a viewing distance of 20 inches, for example, we wouldn't need more than 4 lp/mm on-print, after enlargement (half of the 8 lp/mm needed to survive closer scrutiny at 10 inches).

Imagine for this discussion that we are making a 9x enlargement from a 6x7cm negative (a 20x24-inch print).
The f-stop at which the diameter of diffraction's Airy disks will become resolvable (stopping down) in a 20x24-inch print made from a 6x7cm negative for viewing at a distance of 20 inches (assuming the best eyes in our audience can resolve no more than 8 lp/mm at 10 inches), will be:

Maximum N = 1 / 4 / 9 / 0.00135383 = 20.5 (or f/20.5)

So we might get away with using f/22, but must definitely avoid f/32 and smaller apertures if we are to avoid visible diffraction in a 9x enlargement viewed at a distance no closer than 20 inches.

Smaller prints can get away with smaller apertures because the enlargement factor is less. Greater viewing distances can get away with smaller apertures because the required print resolution is less. Using another version of the same formula, again assuming a viewing distance of 20 inches and a desired print resolution of 4 lp/mm, use of f/45 would require that our enlargement factor not exceed:

Max Enlargement Factor = 1 / (desired print resolution * 0.00135383 * N)

Max Enlargement Factor = 1 / (4 * 0.00135383 * 45) = 4.1

So, as long as we don't enlarge the 6x7 negative more than 4.1x (max print size = 9x11.3-inch) and don't view the print any closer than 20 inches, we'll be OK using f/45.

Recommendations: Calculate the f-stops at which diffraction will prevent the resolution you desire in prints at those sizes you intend to make for the formats you work with and keep a list of these f-stops in your camera bag. Resist the temptation to stop down below the calculated f-stop in the quest for additional Depth of Field. What good can come from making the Circles of Confusion smaller at the Near and Far extremes of the subject space when doing so will cause Airy disk diameters to be larger than your largest Circles of Confusion throughout the entire image?

The calculations above might also be performed with a less conservative desired resolution in the final print. My use of the word "desired" allows for some subjective leeway. Since many people can't resolve 8 lp/mm at a distance of 10 inches, you might choose to specify 5 or even 4 lp/mm as your desired resolution for a print viewed at 10 inches. If you want your images to appear extremely sharp to nearly everyone that views them at nose length, I would recommend you stick with a goal of at least 7 lp/mm in the enlargement. If you somehow know in advance that the print will not be viewed any closer than 100 inches, you could make your desired print resolution 1/10th of that desired for viewing at 10 inches (0.5 lp/mm instead of 5 lp/mm, for example). Hint: Billboards can appear sharp when viewed at a distance of 100 yards, so always consider the anticipated viewing distance when selecting a desired print resolution.

Keep in mind that a print may seem acceptable at first glance even when the effects of diffraction are actually visible. Diffraction affects the entire print uniformly, independent of camera to subject distances. At its onset, this image degradation can be difficult to recognize in the absence of a comparison print taken with a wider aperture, laying right along side the print in question.

When Depth of Field is insufficient for a given enlargement factor and viewing distance, we can detect it easily because any Circles of Confusion that have become resolvable to the eye at the near and/or far extremes of subject distance, are obvious against those unresolvable (acceptably small) Circles of Confusion rendered for subjects that lie closer to the plane of sharpest focus within the subject space. We can tell when something is "out of focus" because we have something "in focus" right next to it. But when the entire print has been softened by diffraction, especially just a wee bit, it's likely to go unnoticed without having something to compare it to. If you want to test the math, just make sure the comparison print, taken at a wider aperture, is taken of a subject space that does not actually require the smaller aperture for sufficient Depth of Field. It's best to just shoot a subject that lies entirely in one plane for such comparisons, so that Depth of Field will not be a factor in judging the relative image quality.

See my Tools page for more information about Diffraction: http://home.globalcrossing.net/~zilch0/tools.htm